ASTRONOMY

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Planetary Atmospheres

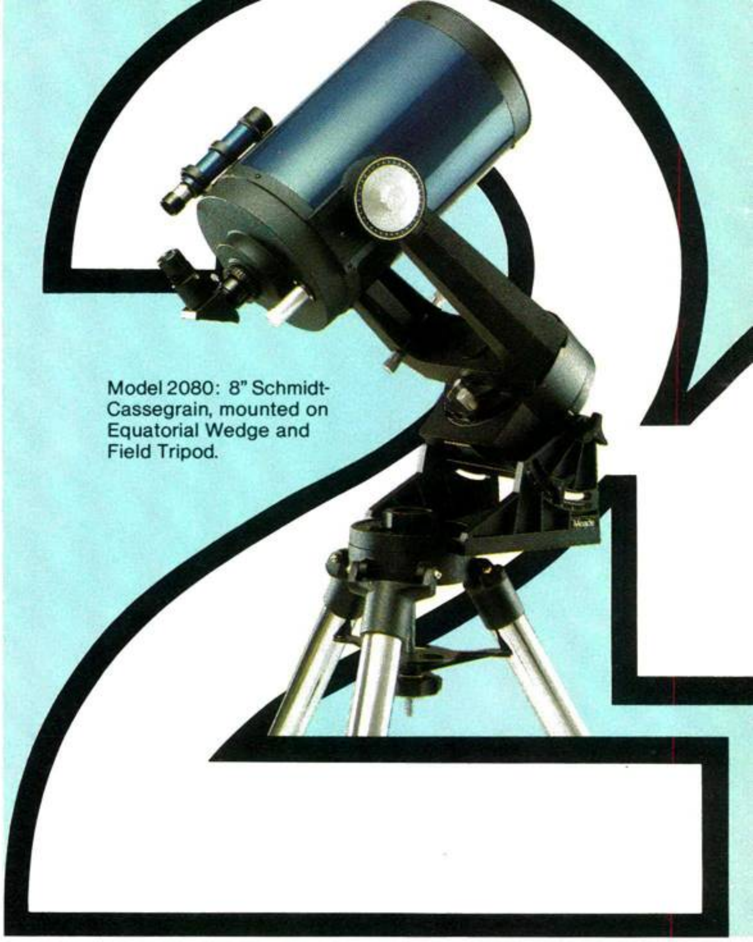
Viewing May's Solar Eclipse

Shuttle MMU Pictorial

ICD# 08070 71574

Testing the MMU

Meade Schmidt-Cassegrain Telescopes: **(1)** 4" Model 2044, with standard-equipment table tripod; **(2)** 8" Model 2080; **(3)** 10" Model 2120.



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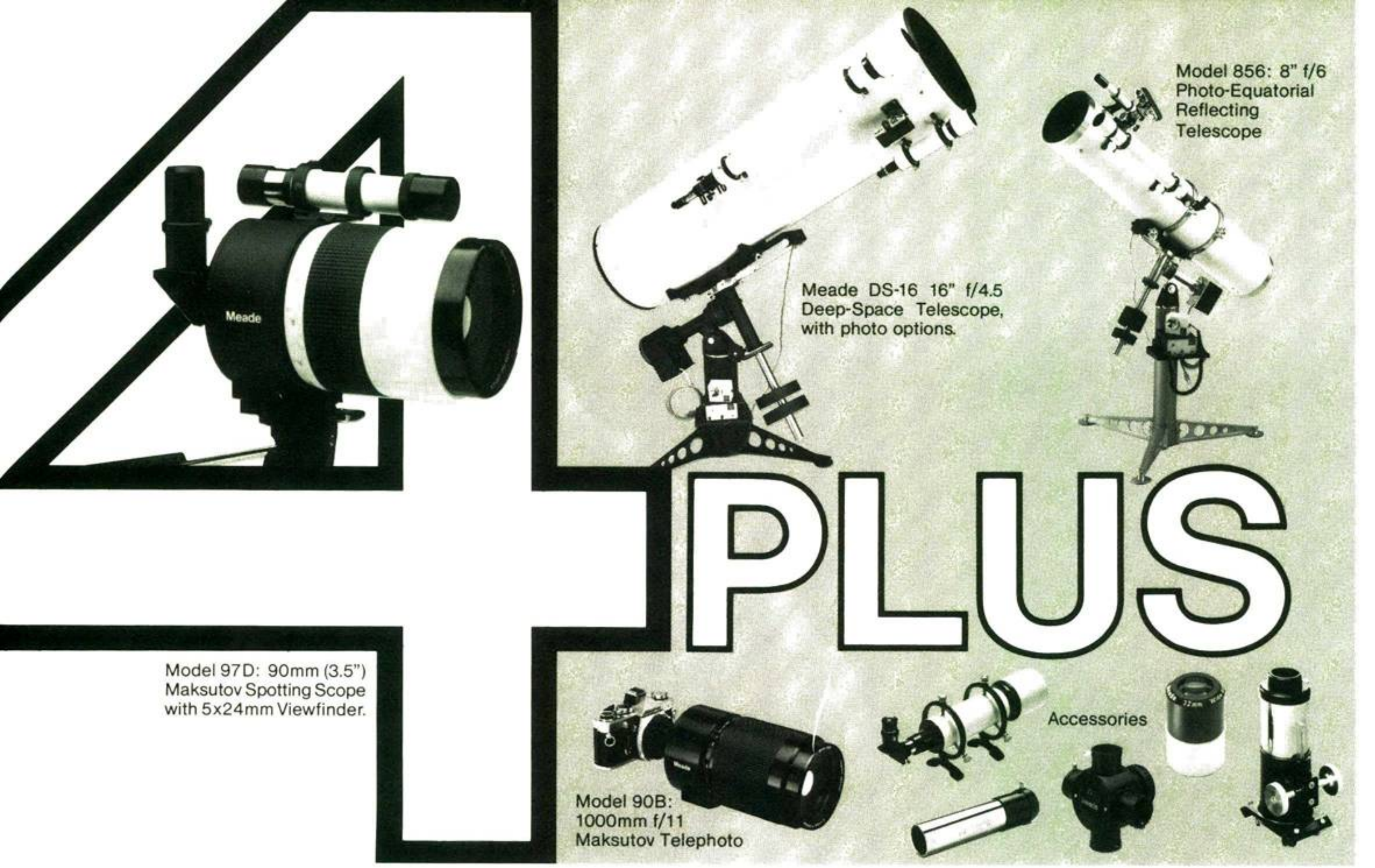

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Cover: Astronaut Bruce McCandless floats against the blue-white backdrop of planet Earth. Strapped into his Manned Maneuvering Unit, a nitrogen-propelled jet-pack, McCandless performed the first untethered "space walk" last February. This month, beginning on page 66, ASTRONOMY brings you highlights of this historic space mission. These pages: McCandless flies free about 70 meters from the Space Shuttle *Challenger*. NASA photos.

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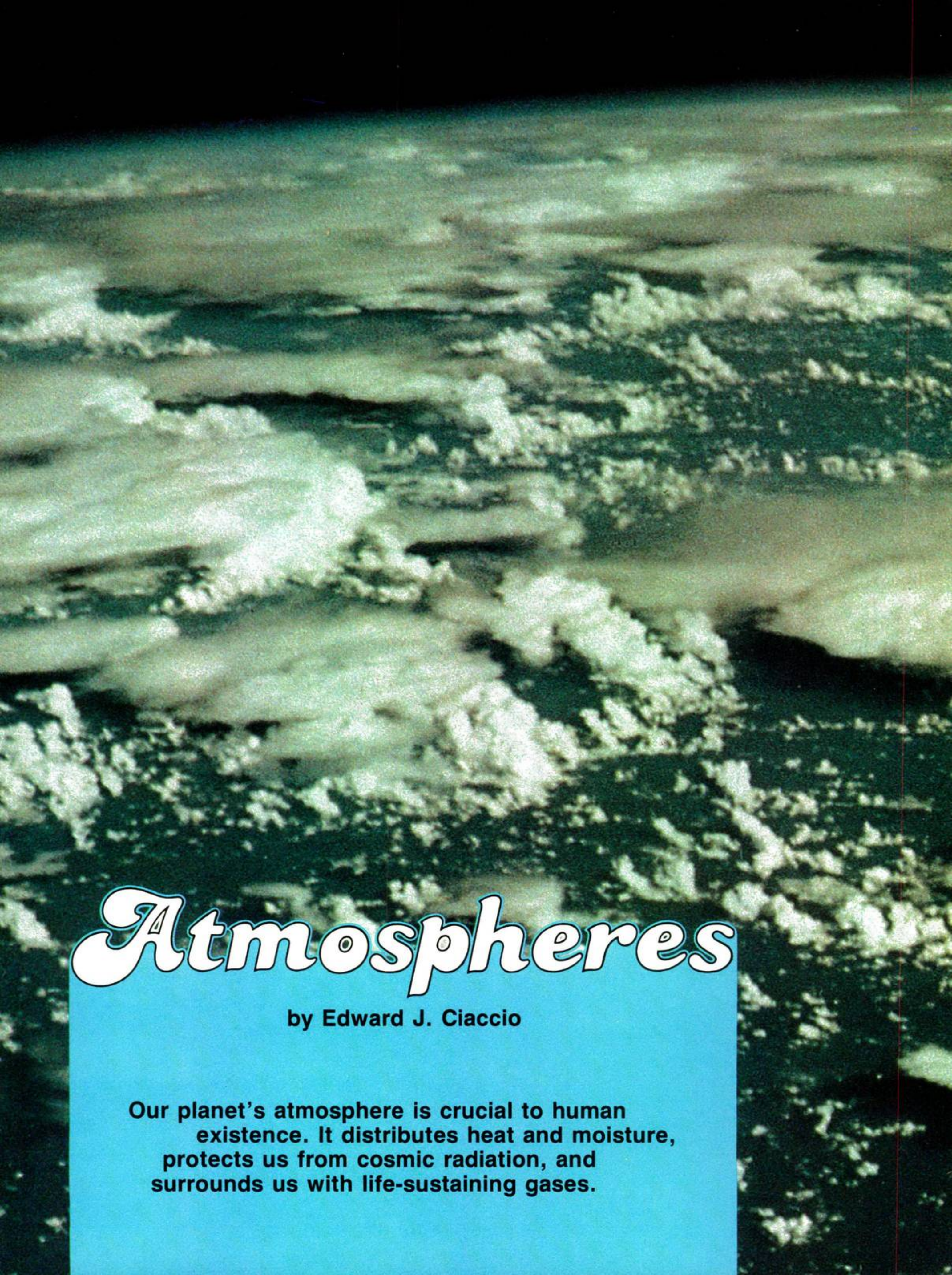
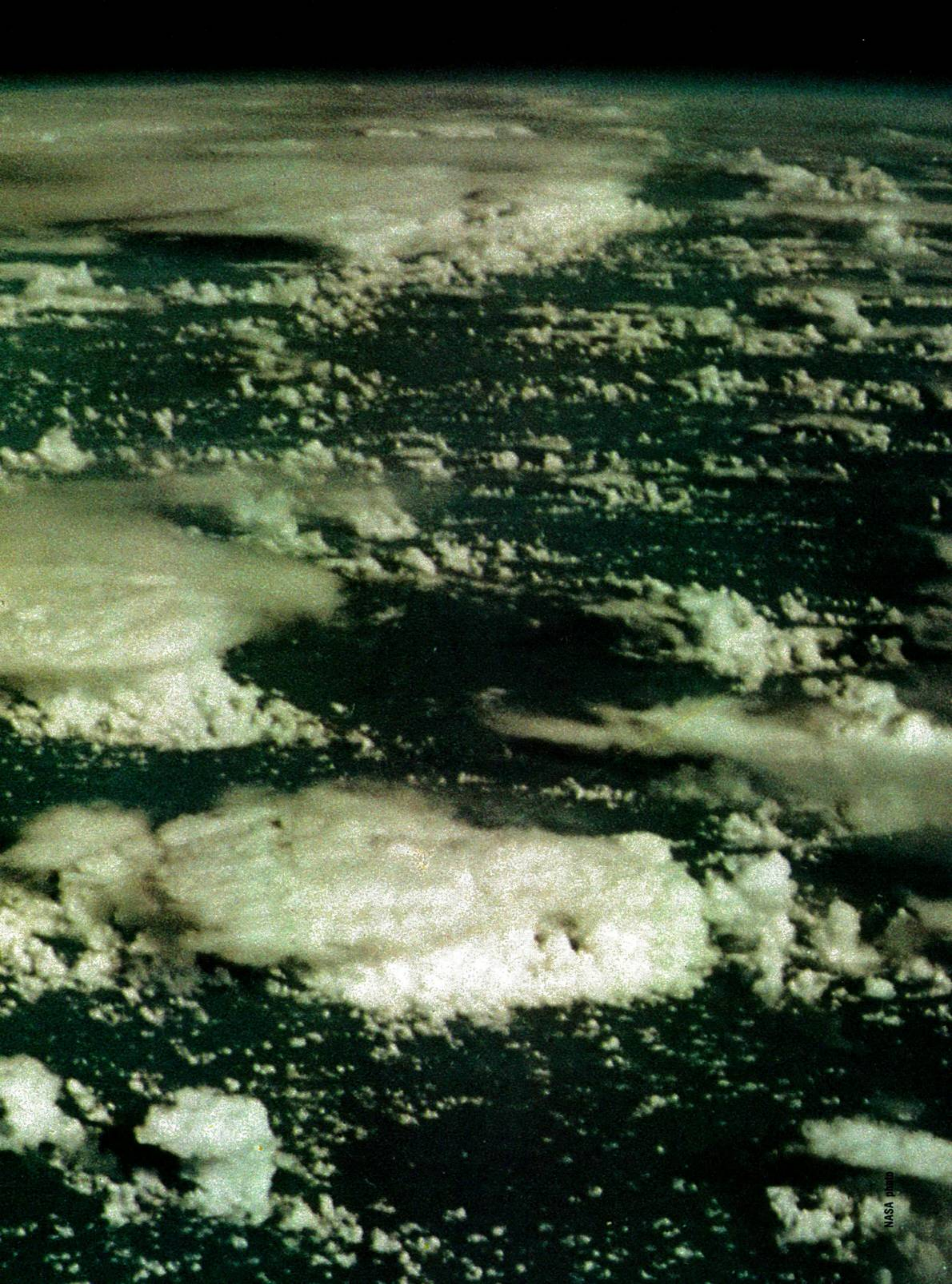


Atmospheres

by Edward J. Ciaccio

Our planet's atmosphere is crucial to human existence. It distributes heat and moisture, protects us from cosmic radiation, and surrounds us with life-sustaining gases.



NASA photo

Understanding the atmospheres of the planets is a goal toward which astronomers and physicists have worked for decades. The ramifications of discovering what makes an atmosphere behave the way it does are tremendous: on Earth, for example, we could improve weather forecasts, minimize damage to crops, and save lives by warning people of impending natural disaster. By comprehending Earth's atmospheric behavior we can also make conclusions about Earth-like planets in general, perhaps even determining the plenitude or rarity of livable planets. Planetary atmospheres differ greatly from planet to planet: Earth's nitrogen-rich atmosphere, bathed in plentiful amounts of cool, life-supporting water, is a stark contrast to Venus' hellish temperatures, high pressure, and noxious clouds of sulfuric acid. Saturn's thick envelope of high-pressure gaseous hydrogen is far different from the atmosphere of its little neighbor Titan, which is composed primarily of nitrogen, methane, and ethane. Each world in our solar system, each different example, has traits similar and dissimilar to the others; by studying them and understanding those likenesses and differences, we can better comprehend our past, present, and future.

Atmospheres are chiefly composed of gas molecules, so understanding atmospheres begins by looking at the behavior of molecules. Gases and liquids share the property of being fluid: they flow across the surfaces of planets, seeking the lowest possible elevation. Individual molecules in a fluid continuously bounce into each other; as the fluid's temperature increases, the molecules move faster and knock into each other more vigorously. This random molecular motion always leaves a certain amount of space between the molecules.

Normally, density — mass divided by volume — decreases as temperature increases because the molecules move faster and push out a bigger space between themselves. But at the bottom of a layer of molecules, the weight of the topmost molecules bears down on those at the bottom, constraining their motion and packing them more tightly. Thus density is also related to pressure — the more molecules in a given space, the more pushing, and the higher the pressure. Pressure, like density, increases with depth in an atmosphere or ocean.

Temperature also varies with depth, but in a much more complicated fashion. Radiation, convection, and conduction — the three ways to transfer heat — all play important roles in heating and cooling atmospheres. Solar radiation can strike a gas molecule and impart energy to it, causing the molecule to speed up, dissociate, ionize, or re-radiate. When a gas molecule dissociates, it breaks up into atoms or smaller molecules. When it is ionized, electrons become stripped from their atoms. The second transfer method, convection, occurs when a heated parcel of gas — of lower density than its surroundings — rises just like a hot air balloon. The third process, conduction, tends to equalize temperatures: when cool masses collide with warm ones, the cooler masses heat up and the warmer ones cool down.

A planet's surface materials can also influence the atmosphere's temperature. Earth's oceans, for instance, slowly grow warmer during the summer by absorbing heat from the air and sunlight. During winter, the oceans retain the absorbed heat and pass it back to the air that flows over them. This results in a moderation of temperatures near oceans and other large bodies of water.

A planet's reflectivity — its albedo — also affects the temperature of its atmosphere. Planets with high albedos reflect a great amount of the sunlight they receive; low albedo planets absorb much of it. This absorbed heat eventually is transferred to the planet's atmosphere. Even the atmosphere itself is a factor if it is opaque and contains clouds or dust particles, which scatter or absorb sunlight and heat the gas.

Furthermore, different molecules absorb solar radiation differently. Some absorb the infrared portion of the electromagnetic spectrum — heat radiation — more easily than others. Carbon dioxide is an especially good absorber of long-wavelength infrared radiation and is largely responsible for the oven-like high temperatures on Venus. Solar energy is trapped because, when sunlight is absorbed, the energy is re-radiated at longer wavelengths which do not readily escape the atmosphere. The result? Venus heats up — to a blistering 700° K. The CO_2 molecules effectively convert the Sun's radiative energy to the thermal energy of their own motion.

Another important factor affecting a planetary atmosphere is how its air moves about. Air currents play a large role in producing the weather we experience on Earth. The movement of warm, moist air over cooler air causes precipitation in the form of ice or water droplets. Winds driven by convection also transport hot and cold air across the surface of our globe, moderating the temperature extremes of summer and winter. One important factor in atmospheric circulation is the Coriolis effect. The Earth's equator (and the air masses above it) move eastward at about 1000 mph. When these air masses move away from the equator toward the slower moving mid-latitudes, they appear to race ahead and shift eastward. The Coriolis effect is responsible for the motions of air in cyclonic storms.

Higher gas densities, such as those found in the lower atmosphere of Venus, modify the weather to such a great extent that this hot planet has little, if any, variation in temperature across its surface. Near the other extreme, in a thin atmosphere such as Mars', winds do very little to change atmospheric temperatures: there are great extremes in martian meteorology between day and night and summer and winter. Summer and winter temperatures on Earth differ by about 100° F; on Mars the difference is often 300° F.

Winds exist because of differences of pressure and temperature at the surface and in the atmosphere of a planet. Gas currents push from areas of high pressure to areas of low pressure. High-pressure systems form where cold air prevails; cold air has a high density and therefore a high pressure. It spirals outward to regions of warm, low-density air. We call the collective result of these flows "weather."

Earth, Mars, Venus

Now that we've examined some of the basic factors that govern how an atmosphere behaves, let's look at the atmospheres of individual planets.

The inner four planets and their satellites are composed of relatively dense metals and minerals. The two smallest, the Moon and Mercury — unlike Earth, Mars, and Venus — have no appreciable atmospheres. Mercury does pluck a small amount of hydrogen and helium from the solar wind, but these gases readily escape again,

The Pioneer Venus orbiter made this ultraviolet image of whirling clouds — principally composed of sulfuric acid droplets — which circuit the planet once every four days. NASA photo.

primarily because of Mercury's small size and high surface temperature. Mercury's "atmosphere" is actually an excellent vacuum by earthly standards.

Earth's atmosphere consists chiefly of nitrogen (78%) and oxygen (21%). The atmospheres of Venus and Mars, on the other hand, contain primarily carbon dioxide. In all three atmospheres, however, water plays an important role. On Earth and Mars, much of it exists in surface reservoirs — oceans and polar ice caps on Earth and the northern polar ice cap on Mars. Venus' high surface temperature precludes the existence of liquid water; the tiny amount of H_2O on our sister planet is confined to the atmosphere.

At the upper edge of an atmosphere, solar ultraviolet radiation dissociates gaseous molecules into molecular fragments called radicals. These remain stable only at the low densities present in the upper atmospheres; they quickly react when they collide with other particles. Water dissociates into hydrogen (H) and hydroxyl (OH) radicals. The light H radical often escapes into space, while the heavier OH radical can eventually react with a variety of particles to form a new molecule. On Venus, where sulfur dioxide (SO_2) is an important constituent, two OH radicals often combine with SO_2 to form H_2SO_4, better known as sulfuric acid. This accounts for the thick sulfuric acid clouds that hide the surface of Venus. (On Earth, sulfur dioxide produced from volcanoes and from burning sulfur-rich coal also turns into sulfuric acid and falls to the ground in the form of acid rain.)

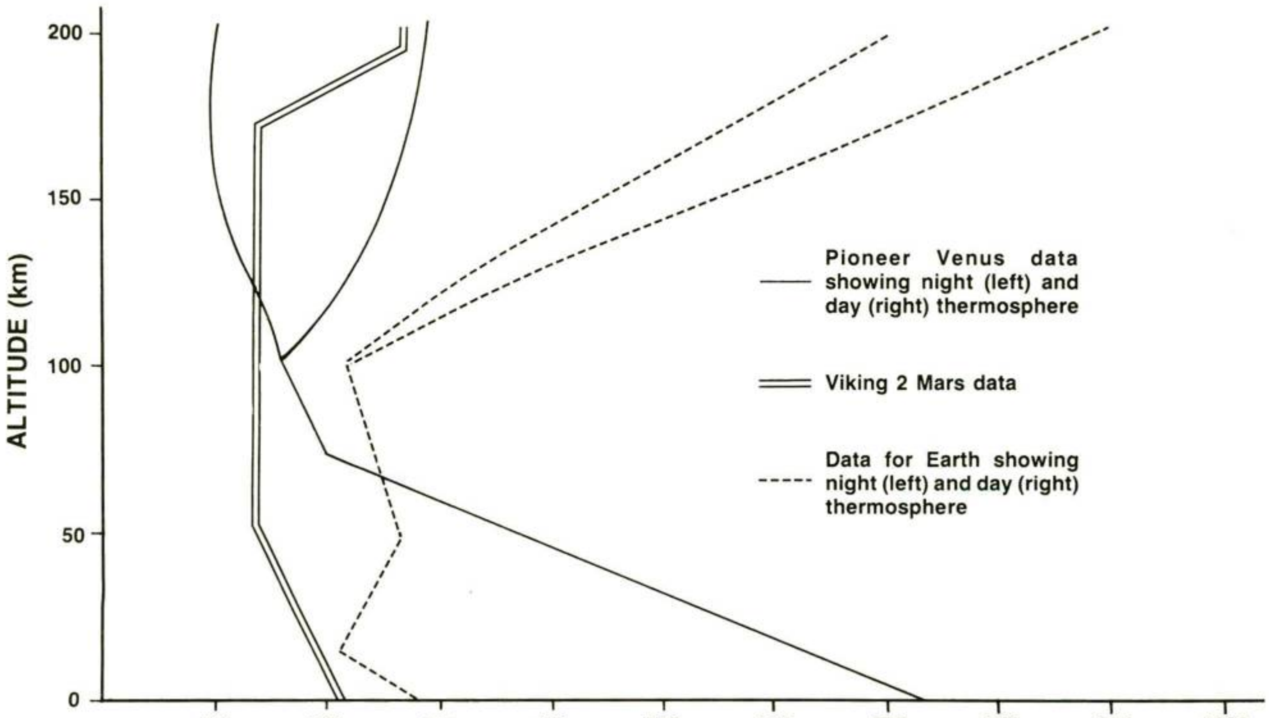
Morning water vapor condenses in Mars' southern hemisphere. The thin martian atmosphere holds small amounts of water and large amounts of carbon dioxide. NASA photo.

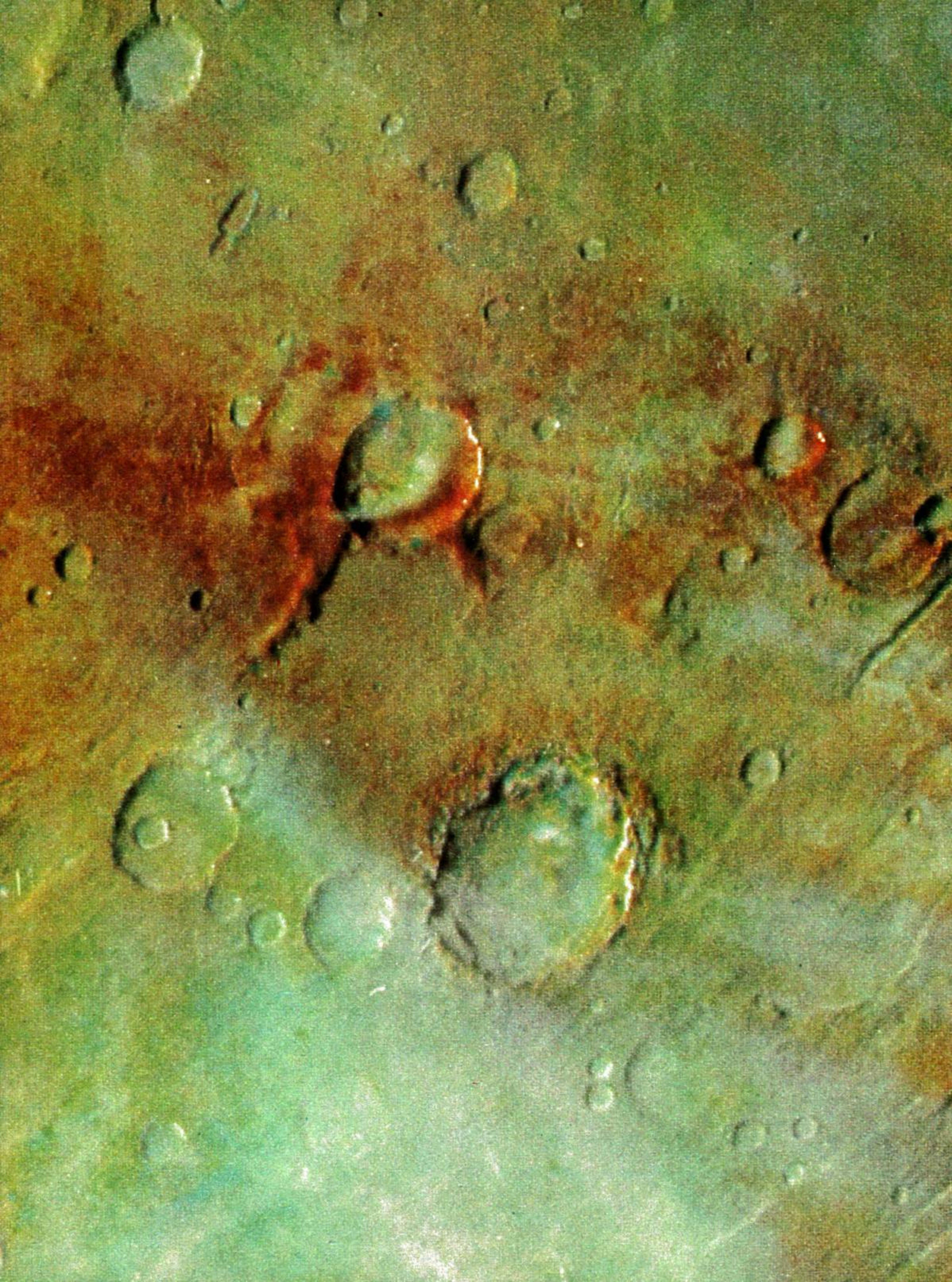
Scientists classify the planets' atmospheres according to their temperature profile — the change in atmospheric temperature with height. On any given planet, temperature may increase with height in some levels and decrease with height in others. The atmospheres can also differ by the amount of mixing that goes on within them.

A number of distinct levels — the scheme is based on Earth's atmosphere — exist in every planetary atmosphere. The highest is the *exosphere*, the outer edge of a planetary envelope. This is the region above which at least half of the upward-moving molecules do not collide with another, but continue freely into space. Earth's exosphere begins some 500 kilometers above the surface. Its temperature plays a critical role in the evolution of an atmosphere: with high exospheric temperatures come rapid molecular motion, resulting in significant numbers of molecules escaping into space.

Below the exosphere lies the *thermosphere*, the outermost region of an atmosphere where temperature increases with height. On Earth the thermosphere lies between 100 and 500 kilometers above the surface. Temperatures escalate rapidly up through the thermosphere, from about 200° K at its bottom to 500° K or even 2000° K at its top. In this region the molecules can move substantial distances before colliding with other molecules. In this situation, similar gases stratify, concentrating in layers, without much vertical mixing. The *ionosphere* is that part of the thermosphere in which electrically charged particles, or ions, abound. An ion can be a negatively-charged electron, positively-charged atom, or a molecule missing electrons as a result of collisions with photons. Earth's ionosphere contains neutral atoms and molecules, with an enhanced number of ions — O+,

Temperature Profiles of Venus, Earth, and Mars



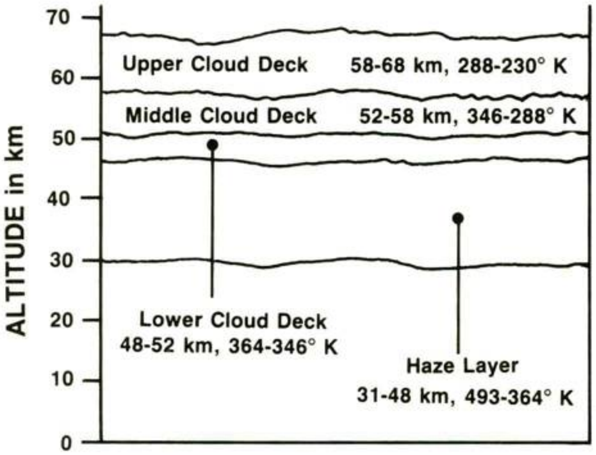


O_2+, NO+ — plus electrons. It is so filled with ions that it is electrically conductive and therefore affects radio waves. This property of the ionosphere allows radio broadcasts over large distances via "bounce beaming."

The next lower layer in an atmosphere is the *mesosphere*, which on Earth begins at 50 kilometers and extends to 100 kilometers. Occasionally clouds in the mesosphere become visible during twilight. These clouds are normally too tenuous to be visible, but sometimes reveal themselves when the Earth is in darkness and the mesosphere still sunlit — hence they are called noctilucent clouds.

At the base of Earth's mesosphere is the *stratosphere*, a region characterized by a temperature inversion and smooth high-velocity winds. This area contains the ozone (O_3) layer, where ultraviolet radiation from the Sun disassociates oxygen molecules (O_2) into pairs of single oxygen atoms. The atoms may then combine with other oxygen molecules to form ozone, which itself absorbs ultraviolet sunlight. The stratosphere is an anomalously hot region, and because the warmer, less dense air stays on top, it is stable and stratified. Other planets do not have an ozone layer. The ozone is particularly important because, without its protection, we would experience lethal doses of ultraviolet radiation!

Characteristics of the Venusian Atmosphere



The region in which the temperature gradient approaches zero is the tropopause; below it lies the *troposphere*, in which turbulent wind motions and large amounts of chemical mixing occurs. Earth's troposphere extends only about 10 kilometers above sea level and contains all of our planet's life — even the top of Mount Everest (8.8 km) lies in this region. Convection occurs readily in the troposphere; temperatures decrease with increasing altitude and parcels of hot, low-density air are buoyant. Virtually all the atmosphere's water — clouds, water vapor, precipitation, and surface water — lies within the troposphere. Clouds cover about 50 percent of Earth's surface; they form when water evaporates from the surface and rises until its vapor pressure — a measure of the number of molecules energetic enough to escape from a liquid and form a gas — equals the atmospheric pressure. At that point, the water vapor condenses to form a cloud. The higher the temperature, the greater the number of energetic molecules and the higher the vapor pressure. Once in the air, water is just another species of gas molecules. Complex and not completely understood processes can cause water particles to coalesce, eventually becoming large enough to drop to the ground as snow or rain.

Solar radiation reaches (and passes through) Earth's troposphere primarily as visible light. The atmosphere's chief constituents — nitrogen, oxygen, argon, water, and carbon dioxide — are transparent to visible light, so when light strikes the ground it is either reflected back to space or absorbed. The absorbed energy is re-radiated at infrared wavelengths. To a lesser degree than Venus, our atmosphere is transparent to re-radiated infrared energy; some is absorbed by carbon dioxide and some by water vapor and clouds. Water — as well as carbon dioxide — heats up after absorbing the infrared radiation. Most of this heating occurs near the bottom of the troposphere due to the warm ground and large amount of heat-absorbing moisture. This keeps the temperature fairly high in the low troposphere. In this process, water vapor plays an all-important role. Where water abounds, heat is retained; where it doesn't, heat escapes. As anyone who has camped in the desert can testify, once the Sun goes down, evenings turn chilly as residual heat from the surface radiates into space.

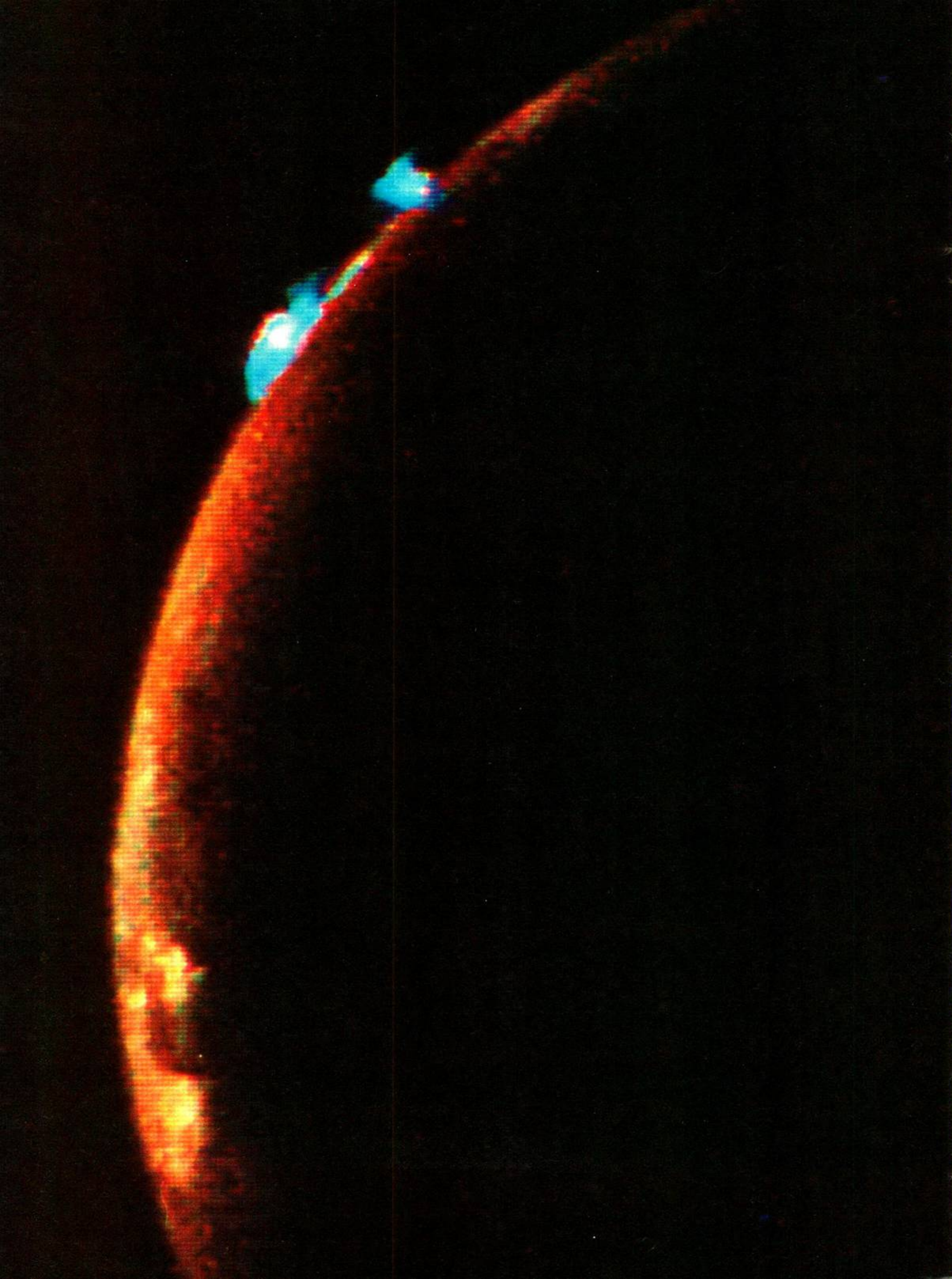
Let's now look at the other terrestrial planets, which all show important differences and similarities to Earth's atmospheric composition. Mars and Venus also possess well defined tropospheres and thermospheres. Little ozone — if any — exists at mid-atmospheric levels on Mars and Venus, so they don't have a warm stratosphere like Earth's. However, like Earth, their tropospheres form as surface heat transfers to the lower atmosphere.

Venus' atmosphere, in fact, may behave in a manner similar to the commercial method used to produce sulfuric acid. This process yields the byproducts sulfuric acid and nitrosylsulfuric acid ($NOHSO_4$). This molecule absorbs ultraviolet light where sulfur dioxide doesn't, and could account for the observed spectrum. Venus' middle cloud layer is probably composed of sulfuric acid and some crystalline substance, perhaps nitrosylsulfuric acid.

Like Venus and Earth, Mars has clouds in its troposphere, but they are thin. Both H_2O and CO_2 exist as ice particles, particularly in the winter polar regions. During the morning a water-ice fog often forms within canyons. A thin layer of ozone exists in the martian troposphere itself, near the surface. This is particularly true over the polar regions, where most of the water is frozen. With slightly warmer temperatures, the ozone layer becomes thinner yet as gaseous H_2O dissociates into hydrogen plus two hydroxl radicals, which destroy ozone.

On Mars, in addition to local, small-scale pressure changes, seasonal effects are tremendously important. The winter solstice marks the beginning of winter in Mars' northern hemisphere; in fact it signifies the shortest day, just as December 22 is normally the shortest day in Earth's northern hemisphere. At the same time, the martian southern hemisphere is beginning summer and is experiencing its *longest* days of the year.

Cyclonic storms and swirling turbulent winds on Jupiter's equator routinely reach velocities of several hundred kilometers per second. NASA photo.



Mars' two hemispheres undergo radically different temperature regimes due to the planet's eccentric orbit. Southern summer occurs around perihelion — closest approach to the Sun — and thus is quite warm. Likewise, the southern winter — happening at aphelion — is very cold. In the north, the coincidences work to moderate the extremes; the northern winter is relatively mild and the summer fairly cool. In fact, northern summer temperatures are cool enough to prevent H_2O from evaporating at the north pole. Mars keeps its north polar water-ice cap during northern summer, but its south polar cap, subjected to a warm southern summer, melts.

This melting of the southern polar cap radically changes the atmospheric pressure on Mars, from about 6 mb to as much as 9 mb, providing enough CO_2 is available. CO_2 condenses at the north pole, but there's a lag in this condensation, so lots of CO_2 floats in the atmosphere, creating high pressure. As more and more CO_2 condenses at the north pole, the atmospheric pressure drops until near northern spring equinox, when all the CO_2 has condensed. A second maximum in pressure occurs around the northern hemisphere summer solstice, and is caused by sublimation of north pole CO_2, while CO_2 and H_2O have not yet condensed at the south pole. This maximum is not as significant as perihelion maximum. This is because during the cooler northern summer, less CO_2 sublimates than during the southern summer.

Polar low-pressure systems form during winter, when CO_2 condenses. Consequently, large-scale wind currents flow toward the martian north pole during northern winter, and toward the south pole during southern winter. Particles airborne in these winds, and also in other martian winds, act to erode surface topographic features. Erosion seems to take place slowly on Mars, however, even though winds often equal Earth velocities. One explanation is that the martian wind is too thin to pick up sand grains large enough to cause severe erosion. Instead, tinier, dust-sized particles and their aggregates are more common; they wear down mountains and canyons only very slowly.

Jupiter and Saturn

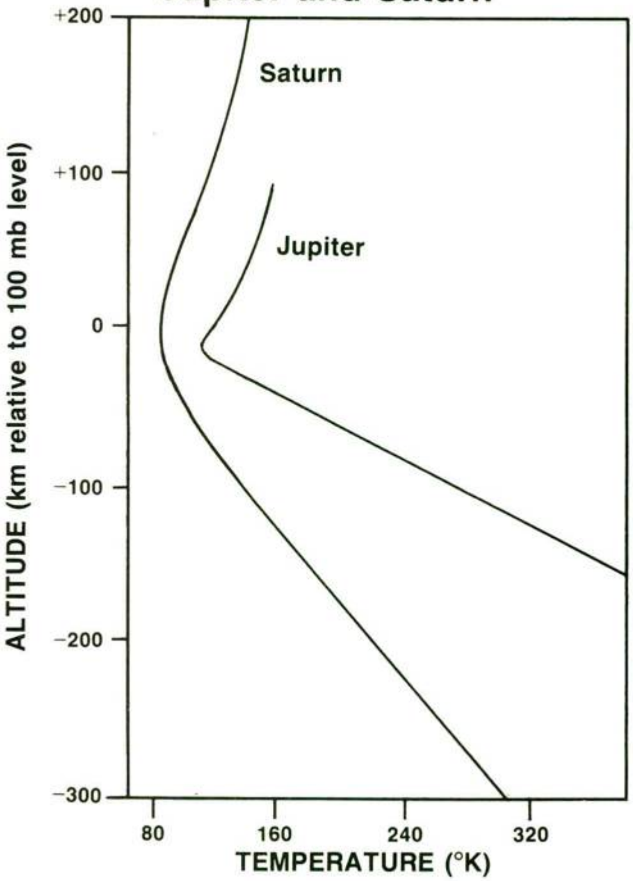
Jupiter and Saturn, the two largest "gas giant" planets, each measure roughly 10 times Earth's diameter and are composed chiefly of hydrogen gas. They are similar in meteorological character, showing fantastic swirling clouds that range the colors of the visible spectrum. Some of the giant swirling features last for decades or even centuries; Jupiter's Great Red Spot, for example, has been observed for more than 300 years. Evidence of giant lightning bolts and aurorae on the night sides of both planets was found by the Voyager spacecraft.

The bulk of the jovian and saturnian atmospheres is hydrogen — about 90 and 94 percent, respectively. Helium (He) is the next most common gas in each atmosphere, followed by trace amounts of methane (CH_4), ammonia (NH_3), and very small quantities of ethane (C_2H_6), acetylene (C_2H_2), water (H_2O), hydrogen cyanide (HCN), carbon monoxide (CO), phosphine (PH_3), and germane (GeH_4). Saturn's atmosphere may also contain methyl acetylene (C_3H_4) and propane (C_3H_8). Some of these gases are deadly toxins. Many are important precursors of life as we know it.

The spectral signatures of these gaseous molecules give us clues to their atmospheric abundances. Hydrogen shows weak absorption, but it must be present in great quantities above the cloud tops on Jupiter; we can see the absorption features in its spectrum, produced by collisions of hydrogen molecules. We can also indirectly infer the presence of He, which has no absorption spectrum itself, by H_2-He collision-induced absorptions of hydrogen. NH_3 produces a line structure in a portion of Jupiter's spectrum. Methane, which accounts for only one percent of Jupiter's atmosphere, nevertheless produces strong absorptions. Saturn's spectrum is similar to Jupiter's, but it doesn't have NH_3 line absorptions, presumably because this molecule freezes out at greater depths in Saturn's colder atmosphere, where it can't be detected.

Since the visible surfaces of Jupiter and Saturn are merely the tops of cloud layers, and since any solid surface is buried beneath thousands of kilometers of hydrogen, it is difficult to speak of "altitudes." Thus planetary scientists more often speak of pressure depths. Just above the clouds, in the jovian and saturnian stratospheres, some aerosols may exist, but the atmospheres are relatively clear. At the cloud tops themselves, the pressures for both planets range from about 500 to 1000 mb, similar to Earth's atmospheric pressures, but the temperatures are much colder. The temperatures of Jupiter and Saturn at these levels are 125° K and 95° K, respectively.

Temperature Profiles of Jupiter and Saturn



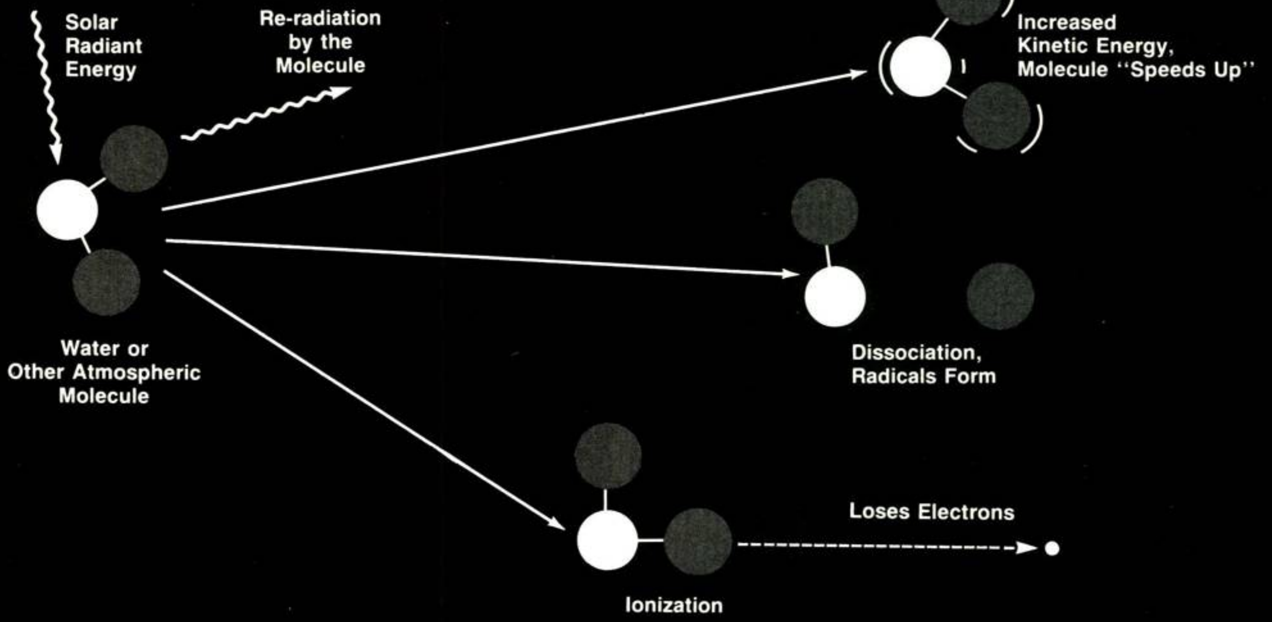
Two towering volcanic plumes appear blue in this Voyager image; they spew volumes of sulfur dioxide into Io's thin atmosphere. NASA photo.

The Planets' Atmospheres

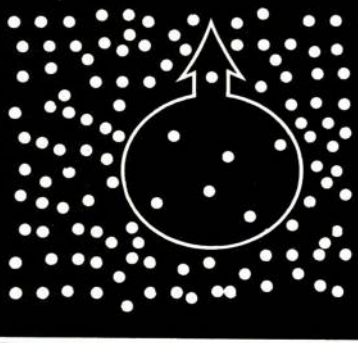
Planet	Basic Constituents	Other Gases	Surface Pressure	Particles
Earth	N_2 (78%), O_2 (21%), Ar (1%)	CO_2, Ne, SO_2, He, H_2	1000 mb	clouds, dust, aerosols
Venus	CO_2 (97%), N_2 (3%)	H_2SO_4, $NOHSO_4$?, H_2O, SO_2, HE, Ne, AR, CO, HCl	9 x 10^4 mb	clouds, aerosols
Mars	CO_2 (95%), N_2 (2.7%), Ar (1.6%)	O_2, CO, H_2O, Ne	6-7 mb	dust, clouds
Jupiter Saturn	H_2 (90%, 94%), He (10%, 6%)	CH_4, NH_3, H_2O, C_2H_6, C_2H_2, HCN, CO, PH_3, GeH_4	no surface	clouds, aerosols
Io	SO_2?	O_2, SO_3, S_2, O, S, CO_2	2 x 10^{-6} mb?	aerosols?
Titan	N_2 (90%), Ar (10%), CH_4 (1%)	H_2, Ne, C_2H_6, C_2H_2, HCN, complex organic polymers	1600 mb	clouds?, dust, aerosols
Uranus Neptune	H_2 (90%), He (10%)	CH_4	no surface	clouds, aerosols
Pluto	CH_4	Ar?, Ne?	0.16 mb	?

Energy Transfer in an Atmosphere

A. Radiation

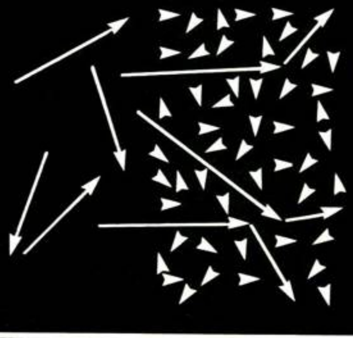

Solar
Radiant
Energy
Re-radiation
by the
Molecule
Increased
Kinetic Energy,
Molecule "Speeds Up"
Water or
Other Atmospheric
Molecule
Dissociation,
Radicals Form
Loses Electrons
Ionization

B. Convection



Surrounded by dense, cold air, a low density, hot air parcel will rise by bouyant forces.

C. Conduction



Hot air molecules move a long distance in a short period of time. When hot and cold air molecules collide, cold air molecules absorb kinetic energy and speed up; hot air molecules lose kinetic energy and slow down.

Since it is twice as close to the Sun, Jupiter receives four times more solar energy than Saturn. For both planets, the energy absorbed decreases at higher latitudes, since polar regions get less sunlight. Saturn's rings shade the surface at low latitudes, so that less energy is absorbed by its atmosphere in these regions. (Jupiter's ring is too thin and small to produce noticeable decreases in absorbed energy.) Thus it is rather striking that both planets emit heat equally across their latitudes. This indicates that heat is transported horizontally at very deep levels. You would expect a thermal gradient governed by latitude if the cloud tops themselves were the site of heat transport. This contrasts with heat transport in Earth's atmosphere. The solid terrestrial surface is an effective barrier against thermal flow, so it all takes place in the relatively thin shell of gas circulating above it.

Temperature profiles for the atmospheres of Jupiter and Saturn show the tropopause of both planets at about the 100 mb level. Jupiter's profile has a stronger gradient with altitude, due to its greater mass and gravitational attraction. For both planets, Voyager measured their tropospheres down to about the one bar level (the cloud tops). This implies that strong convective currents are present. Higher up, near the tropopause, molecular density decreases sufficiently to allow substantial radiation of heat energy to space, so that convection is no longer the chief form of thermal transport. In the stratosphere, temperature increases with height, partially because the density of molecules is low enough to allow significant absorption of sunlight. But a thin absorbing dust may also be present in the stratosphere; it could help heat up this region.

The temperature of Jupiter's thermosphere is about 200° K. But this varies, increasing to 1,200° K where the satellite Io's flux tube — a region of high-energy charged particles — reaches the planet and produces aurorae. Saturn's thermosphere averages about 160° K. Aurorae occur on Saturn as well as on Jupiter; this helps to form complex and colorful hydrocarbons from methane and ammonia, which are later convected toward the equator.

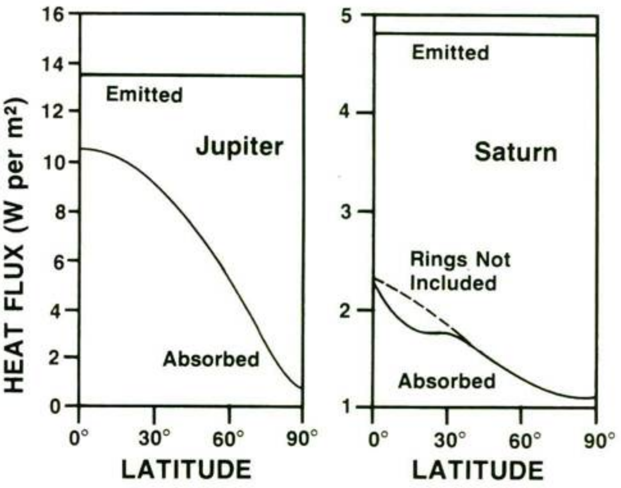
The fantastic colors of Jupiter's clouds correlate well with both temperature and altitude. Blue clouds, the warmest, are located deepest in Jupiter's troposphere. Then come brown, white, and finally the outermost, red clouds, which are very cold. Just like swirling storms on Earth, the Great Red Spot reaches to very high altitudes.

The fury of the winds on Jupiter and Saturn is unparalleled; winds move in latitudinal bands with different speeds and even opposing directions. These zonal jets reach their greatest speeds of several hundred meters per second at equatorial regions. Most wind currents move eastward, although a few have a westward direction. Although the appearance of the jovian banded features often changes drastically with time, there has been virtually no change in the speed or latitude of these jets since the beginning of this century.

The small eddies seen on Jupiter usually last only one or two days, the lifetime of a disturbance being sheared apart by swiftly moving zonal jets. They form when heat from Jupiter's interior or from the Sun warms parcels of atmosphere, making them bouyant. As these swirling features break up, their kinetic energy is transferred to the zonal jets to help maintain them. On Earth, eddies contribute energy to our planet's jet streams, but the streams are not as strong as those on Jupiter (since ours obtain energy only from sunlight and not from Earth's interior).

The eddies increase the velocity of the zonal jets as they transfer kinetic energy to them. That the wind velocities are nearly constant with time implies that the zonal jets are much more massive than the eddies; any increase or decrease in vortex formation changes zonal jet speeds only slowly with time. These massive jets must then extend very deep into Jupiter's atmosphere.

Heat Flux of Jupiter and Saturn



Of all the features of the jovian atmosphere, the Great Red Spot is one of the most intriguing. Three Earths, lined up side by side, could fit inside this giant orangey oval. Large white vortices near the Great Red Spot have been observed for many years. All of these large eddies swirl between opposing zonal jets. Their motion is clockwise in Jupiter's northern hemisphere and counterclockwise in the southern hemisphere. This indicates that they're high-pressure anticyclone systems. These features probably maintain themselves by receiving energy from the smaller, transient vortices, in a manner similar to energy absorption by zonal jets.

Io

Io, the innermost of the four Galilean satellites of Jupiter, is the most volcanically active body in the solar system. Tidal heating from Jupiter powers several volcanoes that spew forth vast quantities of sulfur dioxide gas; the gas condenses as white frost on the surface. The amount of SO_2 gas in the atmosphere depends on the temperature of the surface frost. Higher temperatures increase the vapor pressure and produce a denser atmosphere. Other constituents, formed by photodissociation and chemical reactions, probably exist in Io's tenuous atmosphere: diatomic oxygen (O_2), sulfur trioxide (SO_3), diatomic sulfur vapor (S_2), atomic oxygen (O), monatomic sulfur vapor (S), and carbon dioxide (CO_2).

Io's atmosphere consists only of a thermosphere and an ionosphere. A shell of ionized gas rotating around Jupiter sweeps past Io; it is indeed puzzling why this doesn't sweep away Io's thin ionosphere. Io may have a magnetic field that creates a weak magnetosphere, which could keep the ionosphere from being swept away. But as yet, nothing of this sort has been detected.

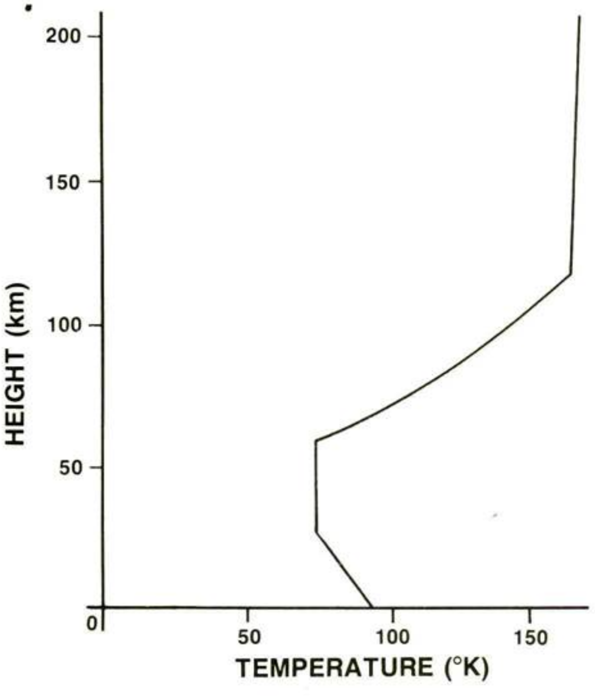
Although Io's ionosphere isn't quickly swept away, it does lose molecules rapidly enough that the atmosphere must be continually replenished from the surface frosts, and therefore from volcanic plume activity. The plumes provide SO_2 to the atmosphere, but they are not directly responsible for SO_2 escape, since even the most powerful volcanoes cannot provide escape velocity to the molecules. However, some powerful process is at work removing molecules from Io's atmosphere; this means that most of the SO_2 inventory is recycled by condensation and mixing at the surface.

Titan

Titan is the second largest moon in the solar system, and the only one that has a significant atmosphere. Its mass is about 1/50 that of Earth's; of this, the solid portion is about equally divided between rock and ice. We cannot see the surface of this unique world, since its atmosphere contains a dense orange haze. Clouds of methane may be present, but if so, they're also lost in the haze.

Titan's first known atmospheric constituent was methane, although it makes up only one percent of Titan's atmosphere. Its early discovery happened because of the prominent, easily identifiable absorption bands present in the infrared spectral region. Other atmospheric constituents include nitrogen in large quantity, argon in small quantity, and neon and hydrogen in trace levels. Tiny quantities of C_2H_6, C_2H_2, HCN, and other organic compounds also appear. This atmosphere, like Earth's, contains abundant nitrogen. Titan's atmosphere is thick and cold: 1600 mb and 95° K at the surface at all latitudes.

Titan's Temperature Profile



It is possible that methane exists as liquid, solid, and gas on the surface of Titan, just like water on Earth. This conjures up a scenario of methane oceans and clouds in a frigid, orange version of Earth's meteorology. There is still no *direct* evidence for methane clouds, but if they exist, they would contain solid or supercooled liquid particles, with dissolved heavier organic molecules.

The dark orange haze may have formed from the byproducts of methane dissociation, a kind of organic pollution that takes place with the aid of the Sun. Methane at the top of Titan's atmosphere dissociates as it absorbs solar ultraviolet light, or ionizes from impact with solar wind electrons. The result includes hydrogen and methane radicals, which combine with each other and with nitrogen. We find the products of these reactions, such as ethane, acetylene, and hydrogen cyanide, in Titan's atmosphere. These may react to create more complex organic molecules and polymers that remain in the atmosphere as a haze for a long time before settling to the surface. Over Titan's history, this layer may have accumulated to a 10 km thickness. If methane oceans exist on the surface, the complex organic compounds would be soluble and would color the oceans orange. As gaseous methane is lost from Titan's thermosphere to produce these compounds, methane frost or liquid vaporizes from the surface.

Nitrogen clouds may be present on Titan, but this is unlikely — even though nitrogen is the most abundant element in its atmosphere. The molecular nitrogen (N_2) may form when ammonia ice sublimates from Titan's surface. When the ammonia molecules reach the upper atmosphere, they dissociate, like methane. The hydrogen escapes to space, while nitrogen atoms combine with each other to form N_2 molecules, as well as organic molecules in the presence of carbon. In most, if not all, of Titan's atmosphere, N_2 exists as a gas, rather than a solid.

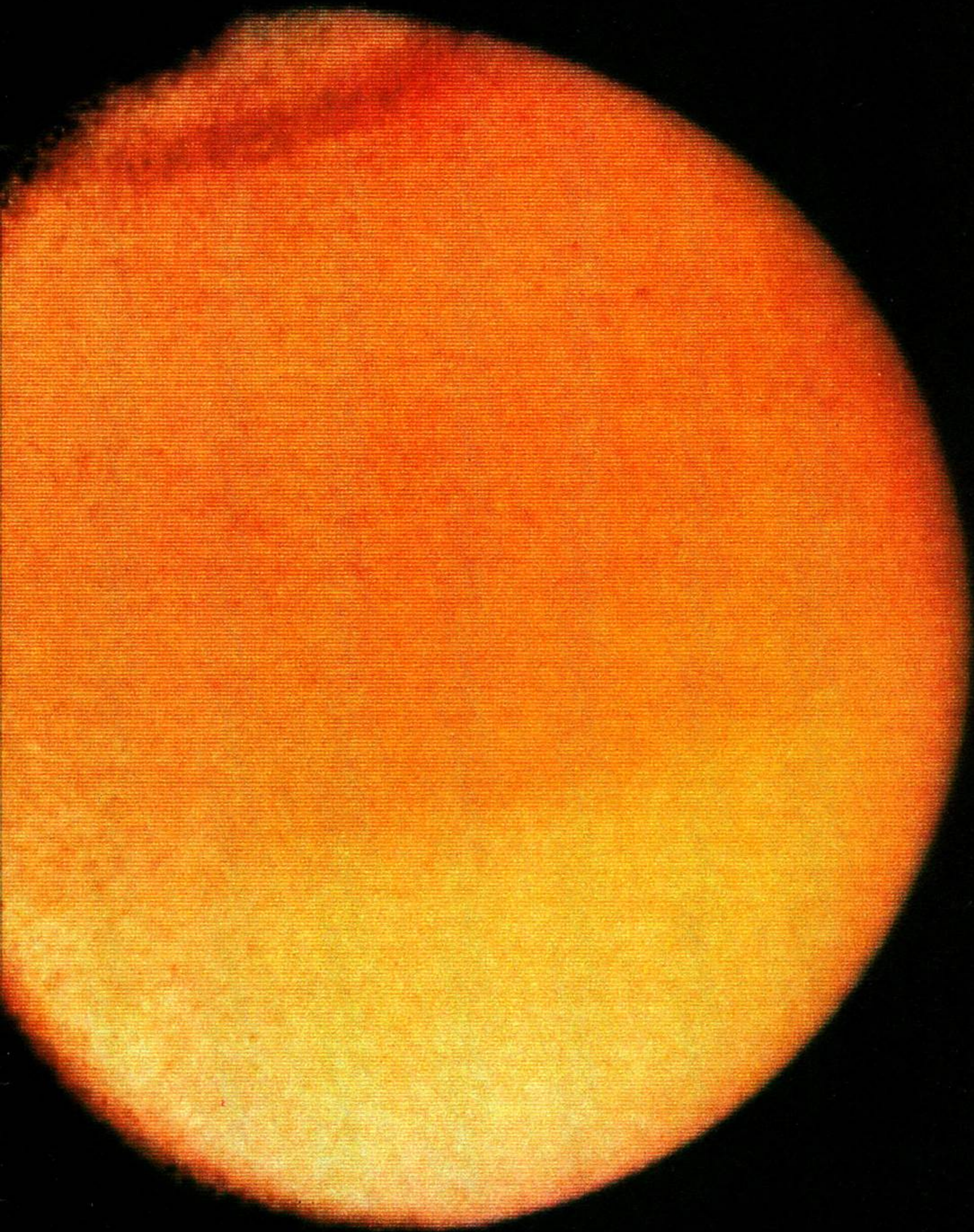
Titan reflects 20 percent of the sunlight striking it, and this high albedo makes it easily visible in small telescopes. But at short ultraviolet wavelengths like 2600 Angstroms, Titan's albedo is only about five percent. Some medium must absorb this energy: nitrogen and methane, which reflect quite readily in this part of the spectrum, can't be responsible. The only plausible absorber is a fine dust called Danielson dust, composed of tiny particles, perhaps 0.5 micron across, that obscure the surface and clouds at visible wavelengths.

The surface temperature of Titan is about 95° K. Although this is cold, it is higher than might be expected. The "greenhouse effect" is at work here: Titan's troposphere is heated near its base, because pressure-induced absorption bands of nitrogen, hydrogen, and methane absorb infrared radiation from Titan's surface. Similar to the carbon dioxide heating on Venus, the energy is not as efficiently re-radiated and ends up contributing to the molecules' motion, increasing their temperature.

Titan, like Earth, has a stratosphere. It extends from 60 km to 120 km in height, with the temperature increasing from 75° K at bottom to 162° K on top. Acetylene (C_2H_2) is the main product of high stratospheric photochemistry, while ethane (C_2H_6) dominates low altitudes. The lower stratosphere is cooler than the upper stratosphere, since not as much infrared sunlight reaches it.

The thermosphere, at 200 km to 1500 km, has a temperature that varies only a few degrees from an average value of about 165° K. This is not easy to explain, since temperatures should be hotter with increasing altitude,

The nitrogen-rich saturnian moon Titan shows the thick orange haze that covers the planet and a dark polar band at north. NASA Voyager photo.



where short-wavelength, dissociating radiation penetrates. Such high-energy radiation is absorbed at upper thermospheric levels; it should not be present at lower levels. A completely satisfactory explanation for this doesn't exist. Within the thermosphere is an ionosphere, composed of N+ and N_2+. These ions are formed mainly by bombardment of N_2 by solar wind electrons. Like nitrogen radicals, some react with methane to form organic compounds.

Speculation abounds regarding life on Titan, since, after all, many of the ingredients are present. One key ingredient is missing, though — oxygen. If primitive living organisms similar to those on Earth inhabited Titan, they would have produced vast quantities of oxygen, as they did on Earth several billion years ago. Titan is too cold for pools of water, which could breed the building blocks of life. Perhaps it is best to regard Titan as a sort of distant cousin of Earth, containing a handful of the characteristics of Earth's primitive atmosphere but not really part of the family.

Uranus and Neptune

The atmospheres of these distant, nearly identical, bluish-green planets are primarily hydrogen, helium, and methane. Like Jupiter, Saturn, and Titan, these mysterious worlds have reducing atmospheres, and they are very distant from the Sun. But no definite bands or swirls have been observed on either of these planets. From Earth, their atmospheres appear quite dull, except for occasional light and dark patches. They differ from Jupiter and Saturn in being significantly smaller (each having about five percent of Jupiter's mass) and denser. In fact, rather than being composed primarily of hydrogen and helium, as are Jupiter and Saturn, the interiors of Uranus and Neptune probably contain significant quantities of the heavier elements that are abundant in our Sun, such as silicon, carbon, oxygen, nitrogen, sulfur, and iron.

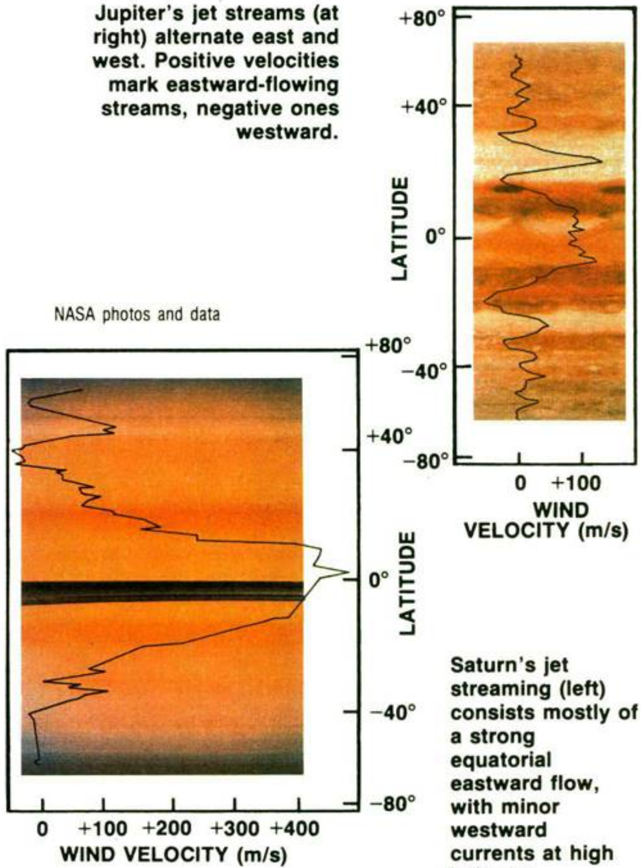
One of the few observable characteristics of these odd worlds is their effective temperatures. We have found that Uranus and Neptune have the same temperature (about 60° K), even though Neptune lies 50 percent farther from the Sun. This may be related to convection of heat from the interiors of these planets. Neptune's "surface" is unquestionably cooler, making it easier for convection to occur. The atmosphere of Uranus, on the other hand, is warmed by the Sun to the point where convection from its interior is blocked. On Uranus, temperature varies with season, especially at higher latitudes. Over the 84-year uranian orbital period, temperature varies about 0.5° K at the equator and 5° K at the poles. No such seasonal variation exists on Neptune.

Uranus and Neptune also differ in the clarity of their atmospheres. Uranus has few aerosol particles, haze, or clouds in its upper atmosphere, while Neptune appears to have copious amounts. Absorption peaks in Neptune's spectrum are broader than uranian ones. The broader peaks are due to light scattering through Neptune's atmosphere, indicating the presence of suspended particles. Since scattering on Uranus is less than that on Neptune, we can see to relatively greater depths in the uranian atmosphere. As is expected, therefore, methane shows stronger — though narrower — absorptions on Uranus, since we are seeing more of it.

Multicolored bands of fast-moving clouds cover Saturn's hydrogen-rich "surface." Saturn's composition closely resembles that of Jupiter. NASA photo.

The haze on Neptune warms its upper atmosphere, creating a temperature inversion. Neptune's aerosol particles vary in numbers relative to the solar wind, since the solar wind correlates with changes in the brightness of Neptune. Although Neptune — and to a lesser extent Uranus — have aerosols in their atmospheres, they contain much less than Jupiter. This gives Uranus and Neptune relatively high albedos. Jupiter, with many aerosols, has an albedo of 58 percent; Neptune has 71 percent, and Uranus 80 percent. Uranus has such high reflectivity that, even though it is about 2 billion miles from us, it can be glimpsed with the naked eye.

Velocities of Jovian and Saturnian Clouds

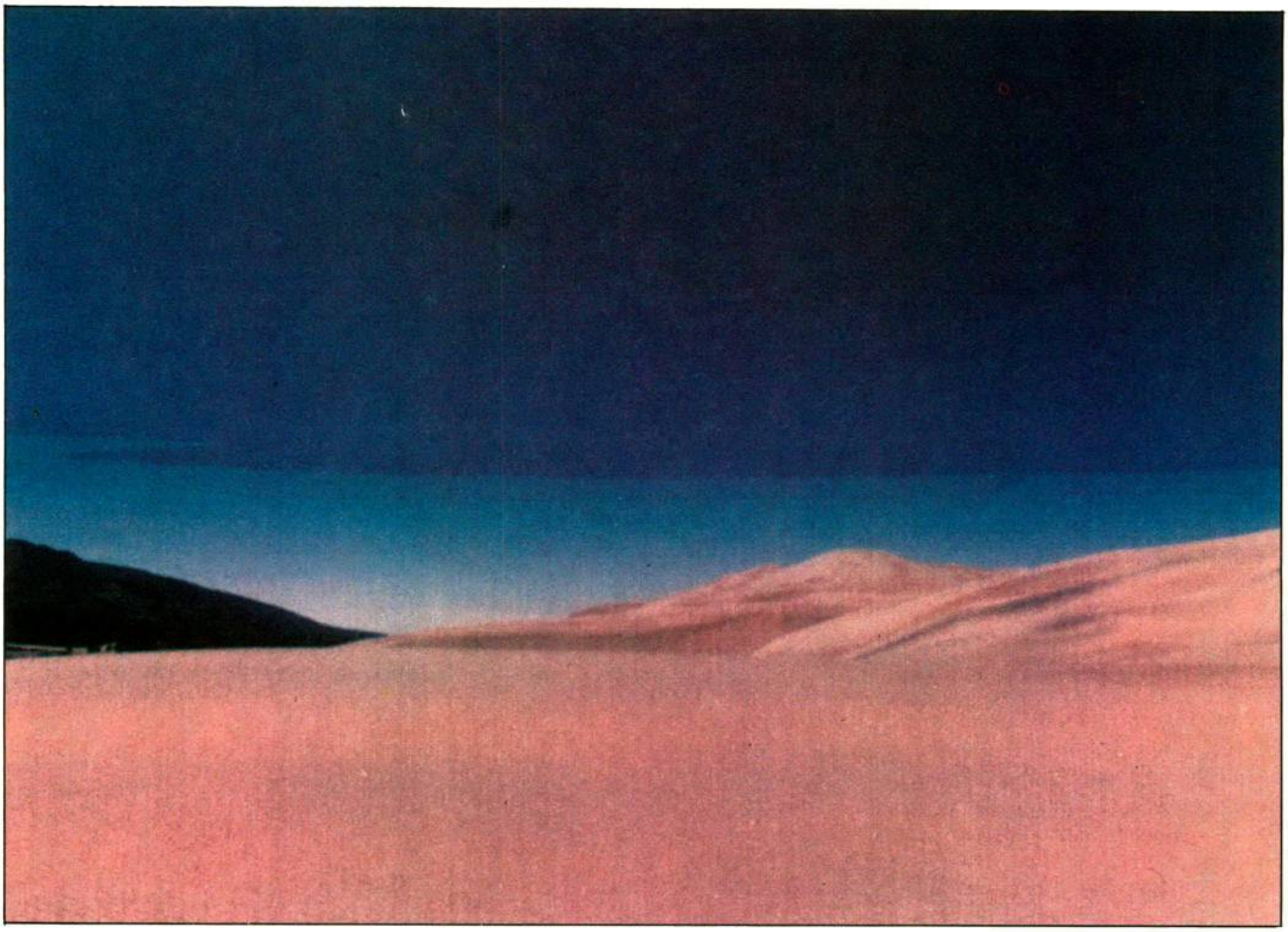


Jupiter's jet streams (at right) alternate east and west. Positive velocities mark eastward-flowing streams, negative ones westward.

NASA photos and data

Saturn's jet streaming (left) consists mostly of a strong equatorial eastward flow, with minor westward currents at high latitudes.

The axis of Uranus' rotation is tipped 98° with respect to its orbital plane, so that it spins nearly on its side. This undoubtedly produces peculiar weather on this strange world. At present, the southern polar region points almost directly toward the Sun and is heated continuously. Since Uranus' orbital period is 84 years, each hemisphere is sunlit for about 42 years, while the other hemisphere lies in darkness. The same phenomenon occurs on Earth, but each pole is bathed in sunlight or darkness for only a few months, owing to Earth's lesser inclination and much shorter orbital period. Neptune's inclination is 29°, similar to Earth's. The upper atmosphere apparently rotates in 17.7 hours, while the lower atmosphere rotates in 18.4 hours. If such values prove to be correct, wind shears on Neptune must be tremendous.



Earth's Mojave Desert may for a moment look like an alien landscape, but sand and deep blue skies betray the terrestrial locale. NASA photo.

Pluto

Does Pluto *have* an atmosphere? This hasn't yet been settled, although evidence will accumulate as more sensitive instruments measure Pluto's infrared spectrum. We see methane absorption, so we know that Pluto has an icy surface, composed at least partially of methane. But what we are more likely seeing is methane gas above an icy surface. The spectral features are known to be saturated, which means they are absorbing completely at a given wavelength, indicative of significant amounts of methane. However, if methane ice on Pluto has a different state of crystallization from that produced in the laboratory, or if it is jumbled on Pluto's surface in an unusual fashion, it could mimic a methane gas spectrum.

One problem that arises from a fairly substantial (estimated 0.15 mb) surface pressure is that Pluto does not appear to be massive enough to retain the gas over the 4.6-billion-year age of the solar system, even at its frigid temperatures. If a heavier gas — such as neon or argon — that would not escape Pluto's atmosphere were present, that could help hold the methane in the atmosphere.

The vapor pressure of 0.15 mb for CH_4 corresponds to a surface temperature of 58° K. Since Pluto is currently nearly at perihelion, these are about the highest pressures and temperatures the planet ever experiences. An icy surface is likely to be in equilibrium with the atmosphere, so as Pluto withdraws from the Sun, much of its atmosphere may freeze onto the surface. Comets exhibit the same phenomenon. As they near the Sun, they develop an "atmosphere" of gases, dust, and ions around them. These disappear as the comets' journeys bring them farther from the Sun.

Pluto's atmosphere is massive enough so that even though the Sun only heats about half of the surface for a long period of time (Pluto's axis is inclined 50° to its orbital plane), the gas will distribute itself nearly evenly around the planet. This means that Pluto's surface temperature will also remain approximately constant on both the day and night sides. Frosts may not be so evenly distributed, since Pluto's visual albedo has diminished over the past several decades, which indicates that surface conditions are changing.

* * *

Though so much about them remains unknown, planetary atmospheres are clearly vital to the study of our solar system. Studying them can not only give us clues to the history of planets, but it can help us understand our own planet's atmosphere. We now realize what a delicate balance exists between gases above and surface below. In this age of progress, when a small technological miscalculation could wreak ecological catastrophe on Earth in the wink of an eye, that understanding is vital.

Edward J. Ciaccio is a medical student at the University of Arizona and an avid amateur astronomer. His last article in ASTRONOMY was "Celestial Debris," in the May 1983 issue. He wishes to thank John R. Spencer and Concetta G. Ciaccio for their assistance in preparing this article.

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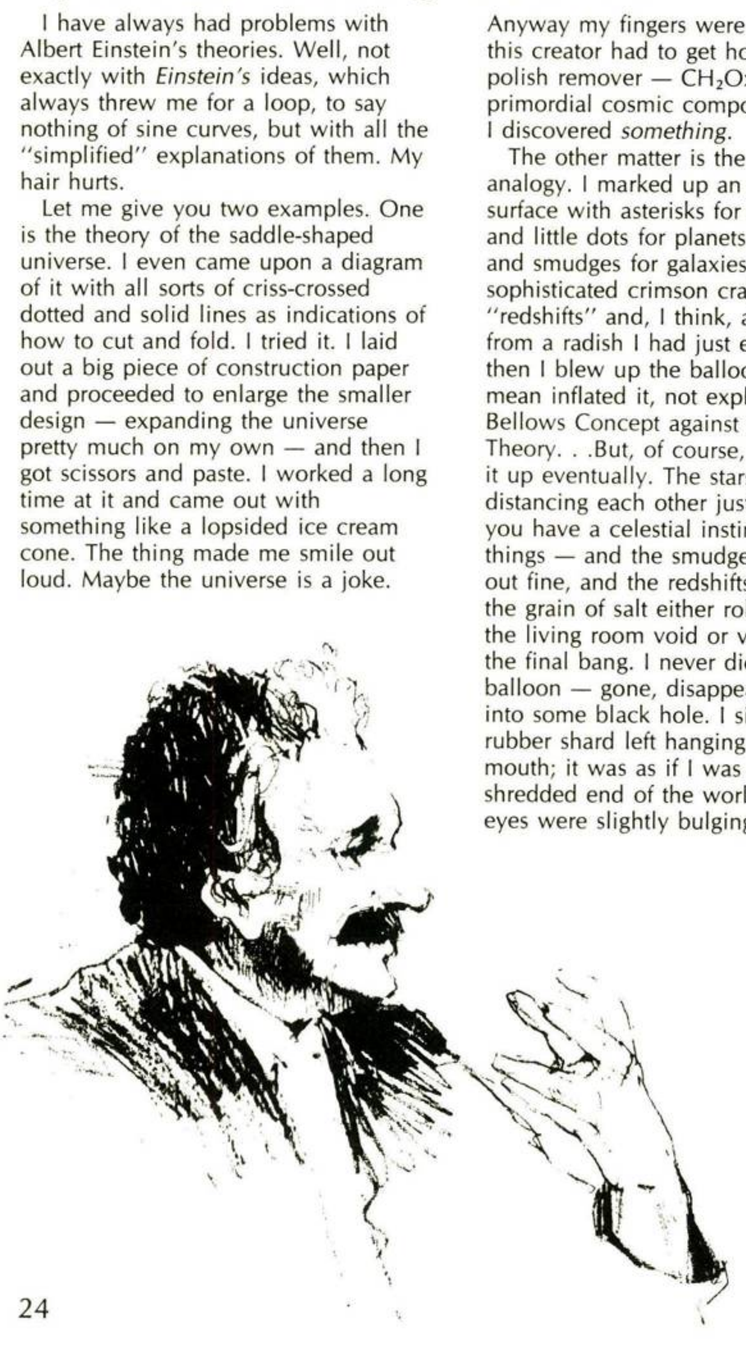
My Little-known Meeting with Einstein

I have always had problems with Albert Einstein's theories. Well, not exactly with *Einstein's* ideas, which always threw me for a loop, to say nothing of sine curves, but with all the "simplified" explanations of them. My hair hurts.

Let me give you two examples. One is the theory of the saddle-shaped universe. I even came upon a diagram of it with all sorts of criss-crossed dotted and solid lines as indications of how to cut and fold. I tried it. I laid out a big piece of construction paper and proceeded to enlarge the smaller design — expanding the universe pretty much on my own — and then I got scissors and paste. I worked a long time at it and came out with something like a lopsided ice cream cone. The thing made me smile out loud. Maybe the universe is a joke. Anyway my fingers were sticky, and this creator had to get hold of nail polish remover — CH_2Ox_4 — maybe a primordial cosmic compound. At least I discovered *something*.

The other matter is the balloon analogy. I marked up an actual balloon surface with asterisks for stars and big and little dots for planets and moons, and smudges for galaxies, and sophisticated crimson crayon marks for "redshifts" and, I think, a grain of salt from a radish I had just eaten; and then I blew up the balloon. No, no, I mean inflated it, not exploded it — the Bellows Concept against the Big Bang Theory. . .But, of course, I did blow it up eventually. The stars were distancing each other just right — if you have a celestial instinct in these things — and the smudges were paling out fine, and the redshifts shifted, and the grain of salt either rolled off into the living room void or vaporized in the final bang. I never did find the balloon — gone, disappeared, zoomed into some black hole. I simply had a rubber shard left hanging from my mouth; it was as if I was drooling the shredded end of the world. Also, my eyes were slightly bulging, I'm told. . . .Well, wasn't something like that true of the Italian contestant for Mr. Universe who inflated a hot water bottle at the last championship meet in South Africa and was wildly cheered for the feat? No one had painted any designs on the bottle, though. But, then, they weren't interested in cosmic understanding, only in proving who had the best build and the strongest lungs in the world.



Barbara Ericksen

Personally, I have only a fair build. My real ignominy is that I keep failing all secret tests in mental strength. That's no surprise to me, of course. The last time I privately experimented, about 30 years ago in Princeton, I was trying out the Doppler Effect on West Witherspoon Street, with my horn held down as I speeded past somebody. It turned out to be our lone Nassau County motorcycle cop, and I got ticketed for speeding. Also for suspicion of drunk driving. But I got out of that, of course — by blowing up a balloon.

I have nothing more to add to impromptu scientific theorizing and demonstrations. Except to volunteer the suggestions that, while I dearly loved the Dr. Einstein I knew, his later disheveled appearance is an event of practically equal importance with the theories of relativity, Brownian motion, and lasers. Objectively speaking, hasn't it occurred to anyone that the good Doctor didn't do a real thing once he gave up his dress suit and wing collar and put on sneakers and sweater? Talk about cause and effect! The plain fact is — if some biographic *Wunderkind* would only leap to the startling truth — that once the world's most famous professor turned careless and went without haircuts and socks, he failed for the rest of his career.

The point is momentous. Look how good he looked in the photograph of 1905: a nice Jewish boy, neat and well groomed and attired. That's exactly the kind of young man to burst upon the

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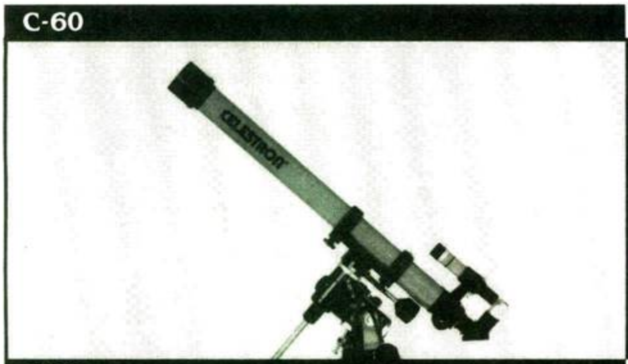

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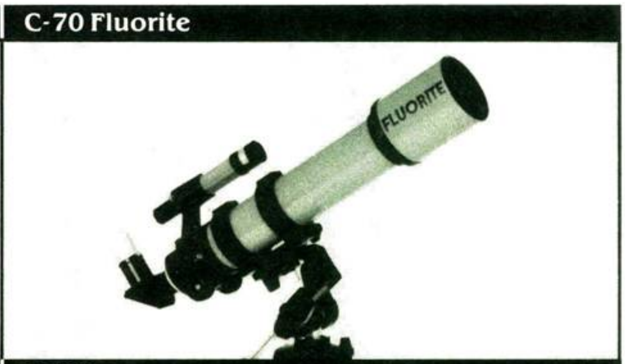

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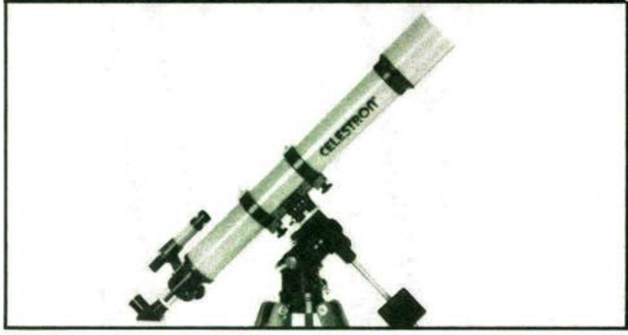

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I never personally met the man in those stirring, early days because, among other drawbacks, I wasn't quite born yet. I met him only in his charming eccentricity — in 1952, to be precise, at the Mercer Street house. I was dying to see him but had no entree. How could anybody specializing in trivial literature walk in on Albert Einstein? But one day I just went over there, that's all. I had a chess set and board under my arms, and I knocked on the door. When it was opened by his housekeeper, I said simply, "I am here to play chess." From the parlor receded to the left beyond the front hall, I could hear the strains of a quavering violin. The woman's eyes blazed. "Chazz!" she cried in a German accent, "never in *this* house," and she started to slam the door on me. Luckily my foot held the door pressure just when Professor Einstein came out from the parlor, violin dangling, asking *"Was ist los?"* I seized the opportunity.

"I am *los-t*. . .I mean, *los*, Herr Doktor. I came to play chess" — I showed him — "not music."

"Wait!" he said to his housekeeper, good Mrs. Brumbacker, who was fetching a heavy umbrella from the hall umbrella stand to pummel me with. *"Lass ihn hereinkommen*, let him come in."

Thus began my little-known personal encounter with the great man who, under the circumstances, was more saint than genius.

"Do you play well?" he asked, showing me into the parlor and motioning me to sit.

"Not extremely. But then you, yourself, are not very good on the violin, sir."

"Can you play *that*?"

"Only as well."

He passed the violin to me and I played a mazurka by Chopin that tailed off into a passage from "Yankee Doodle Dandy."

"You flatted the last," he said.

"I know."

"Set up the pieces," he said.

Tremblingly, I did. We played for about 25 minutes. He won. I was nervous — no excuse at this late date, just a delayed observation. He won, but not overwhelmingly. The fact is that neither one of us was that good. Only, *he* could afford not to be.

"You're not very expert," he said. "On either instrument."

"No, sir. I judge I'm high mediocre."

"Ah?" I believe his eyes shone. "Why are you here?"

"Just to talk, if you have a minute. . . .That's a fib. I meant if you had some more minutes than one."

He nodded. "What is a fib?"

"It is almost a lie. Or it is a lie weakening under pressure."

He liked my souciant honesty. He nodded his leonine head.

"Sehr gut."

"May I talk — about anything but physics?"

"Also gut. Of course. Ask!"

"Why are you speaking out so much for World Government now?" He had been doing so, especially on the Princeton campus, appearing suddenly, attracting any group of students about him. Finding any empty classroom and then just speaking freely.

"I am merely lending the . . . premature question my . . . retrospective prestige. It will tell, later on. Anyone comparable could and should have done so. My friend Sigmund, for example. But he never got to it."

"Karl more or less did."

"Who?"

"Marx."

"But why place me with a figure of my youth instead of my maturity? I would prefer that you think of me as approximating" — I thought we would refer to Freud again — "Mr. Chaplin, if you had to choose someone else. . . . Anyway, I am a Socialist, not a Communist."

"The next best thing," I ventured.

His eyes absolutely twinkled. And he smiled.

"Well *said*. But not quite so well conceived. I presume that you are neither a mathematician nor a metaphysician. Socialists are further than anyone else from Communists *because* they are closest. In the circle of such affairs," he made a delicate round gesture in the air, "the nearest two points are the most distant, since you must go all the way around the human clock to lose charge and then connect. . . . Think a moment. You imagined as much *some* time?"

"Maybe."

Somehow, he had me confessing wisdom.

He stood up now. I followed him, after I had packed my chess set.

He led me toward the door.

"I have nothing more to offer, you must also imagine, nothing more than what I have already done or said. There is never any more than what is really *there*," he said simply. *"Verstehst?"*

I understood. There was no need for me to come again. I had been told a subtle truth, or had been disposed of with the gentlest sauvity.

"Good-bye, Professor."

"Good-bye." He shook my hand. I can metaphorically feel it yet.

I am still struggling with a lopsided saddle-shaped universe that I will never understand the outside or the lopside of. And I can't cope with real or figurative balloons any better than I used to, especially wondering about all the hot air subsequent explainers put inside.

But I won't forget the man himself — that good, wistful and special smile, and those great limpid eyes of the *Herr Professor*, whom I never did have the courage to visit in actuality as in my fantasy, though I *was* there at the time. Like the millions of the rest of us baffled non-scientists, mere amateurs of music and games and life, I treasure the final photograph that has become a presence to so many: the face that kindled a billion more suns than we had ever supposed, saw the light dance, and brooded all convoluted motions of the mind — and bestowed one benign, grandfatherly gaze at me and this miraculous and terrifying world.

Still, I wear shirts and put my tie on as straight as I can. *I'm* no forgivable genius — though my imagination does soar sometimes, in a high mediocre way. I certainly try to get regular haircuts. And my socks, considering what you know about my flights of fancy, probably have a lot to do with holding me down to Earth.

Jesse Bier
Missoula, MT

Paradise Lost?

After playing with telescopes and reading astronomy books all through high school, I had no doubt that I was going to study astronomy when I entered college. Little did I suspect that the university's definition of astronomy could be so different from my own! The stereotypical college freshman is a naive, timid, highly optimistic figure — and I fit the part perfectly. I trotted up to the astronomy department office with my backpack slung over one shoulder — you know, the way the upperclassmen wore their backpacks — and announced my intention, expecting some sort of praise for my wise choice.

"Astronomy major, eh?" The room was dim and smoky, and it took me a moment to locate the black-haired man sitting at his desk. His eyes were dark and fiery. His eyebrows looked like

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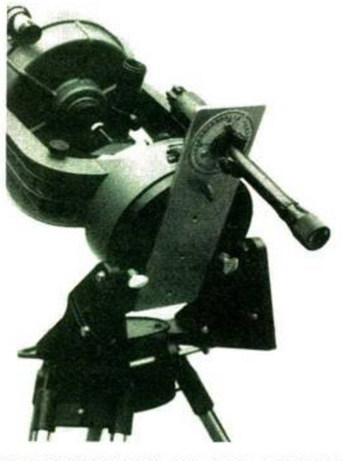

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two handle-bar moustaches somehow mounted on his forehead. He smiled, then sneered; I thought his teeth were pointed.

"You bet!" I said firmly. "How many astronomy courses can I take this semester? I'd really like to get into it as soon as possible."

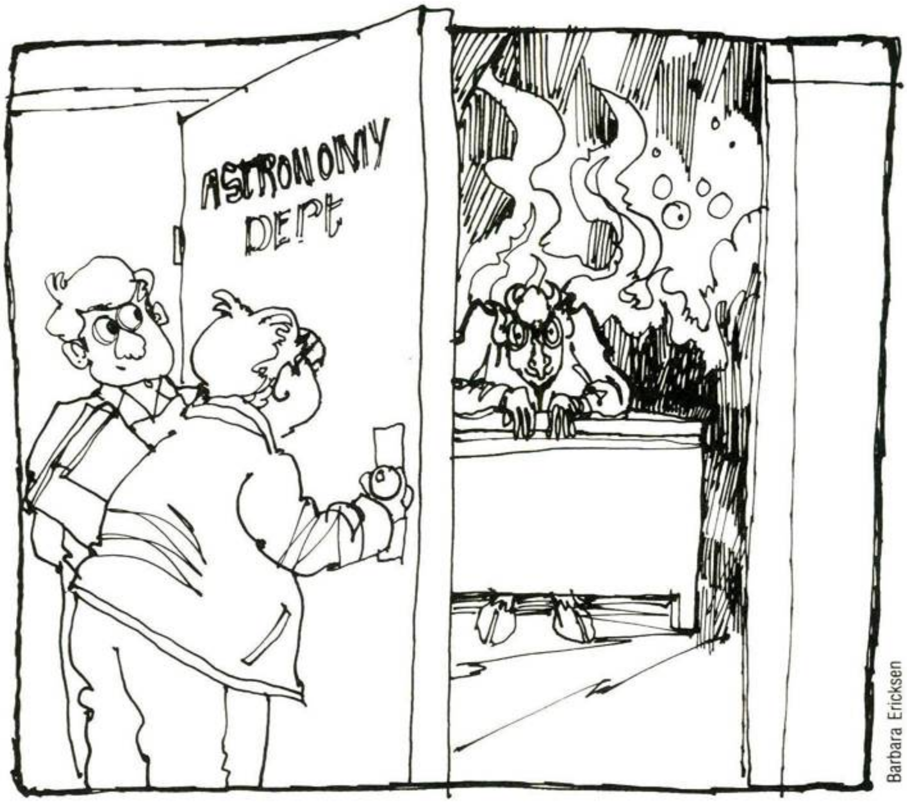
The dark man rose from his seat and strode over to a high shelf on the wall, reaching up to pull down a thick, dusty tome. He carried it over to his desk where a twisted candle flickered weak orange light into the shade, then he slowly turned the pages until he found the place he wanted. The parchment was covered with strange symbols written in a faded, tawny ink. "Freshman? I see." He began to read in a deep voice, as if pronouncing judgement. "It is written that you may take *no* astronomy classes." He looked up at me, fixing his strange gaze. "First, you must take *calculus*."

My heart fell, but I forced a smile. After all, I had expected to make some sacrifices, and calculus had a sort of imposing ring to it. You know, impress your aunts and uncles, new friends, girls. When I entered the classroom, I discovered that calculus was taught by a little Japanese lady who seemed to have learned all her English from a cassette tape while on the plane flying over to the States. It took her 20 minutes to take roll call every morning because the names were so strange to her. Imagine when she tried to lecture on high-level calculus!

The next semester I went to see the little dark man again. This time he already had his book out, as if he had been waiting for me. "Now can I take some astronomy courses?" I snapped. He leered back with a resounding shout, "No. You must take more calculus. And you must also take *physics*." At least physics wouldn't be so bad — lasers, radiation, relativity, nuclear reactions, synchrotrons, and all that stuff! As it turned out, physics was mostly topics like falling rocks and rolling bars. Oh well.

In my third semester I officially became a sophomore, my excuse for naivete and optimism forever left behind. In the office, the dark man ran a pointed fingernail along one set of symbols. "You must take *more* calculus, *more* physics . . . but I can let you take a course in general astronomy, now that you have been initiated."

My joy knew no bounds. Now I could actually study all those things I'd only read about but did not fully understand — quasars, black holes, neutron stars, planetary nebulae, pulsars, the Big Bang, supernovae, X-ray sources . . . the things that astronomy is all about! Unfortunately, the astronomy professors seemed more interested in blackbody curves, the conservation of angular momentum, stellar stability equations, and the difference between intensity and flux than with *exciting* stuff. After gritting through this entire semester where I seemed to be doing more mathematics than I ever did in calculus class, I stormed back into the astronomy office. After all, now I was a sophomore, and didn't think I had to follow rules.



Barbara Ericksen

"I've had it!" I snarled. "All I'm doing is physics and calculus! I want to do some *real* astronomy!"

The dark man did not try to control his anger, as if he had had quite enough of obnoxious undergrads. Fire leaped to his eyes, and he seemed to loom over me in the shadowy darkness of the room. "You *have* been doing real astronomy, silly boy! What do you think astronomy *is*, if not physics and mathematics applied on a grand scale?"

"But I want to learn about black holes, and . . . and pulsars! And the Big Bang! And quasars! You know — the *exciting* stuff! All the rest seems so . . .um. . .er. . .ahh. . .tedious!"

He dove into a full-fledged lecture. "How can *you* talk about tedium? Think about Annie Jump Cannon, who classified 350,000 stellar spectra for the Henry Draper Catalog! Think of John Flamsteed, Britain's first Astronomer Royal, who bought his own instruments for the Greenwich Observatory and then spent countless nights in his observatory, listening to the tick of his pendulum clock so he could time stars crossing the meridian. He marked the positions of 2,935 stars in this way, ultimately producing the most accurate star atlas of his day! And *you* talk of tedium? Think of Johannes Kepler, who used a cumbersome geometrical method to find the distance from Earth to Mars, repeatedly trying to trace the orbit of Mars — he used the method over 70 times and it took him more than five years just to find a rough approximation!

"Astronomy isn't quasars and black holes, boy, any more than archaeology is all digging up fabulous lost cities, or history is all bloody revolutions and conquests! Quasars and black holes are only a tiny part! To be an astronomer you must attain the patience and the will to understand how the universe works. Sometimes it's difficult, and not everybody finds it worthwhile. The time has come for you to make a decision — are you going to be a wishy-washy little boy only interested in 'exciting stuff,' or do you really want to understand the universe? Do you *really* want to be an astronomer?"

I thought long and hard before I made my decision a few years ago. After all, it's a lot of hard work trying to become an astronomer. The painful long hours of study, theories, telescopes, data . . . is it all worth it? I still don't feel like I understand the universe any more than I did before. But I'm sticking with my decision. I want to be an astronomer.

Kevin J. Anderson
Brooklyn, WI

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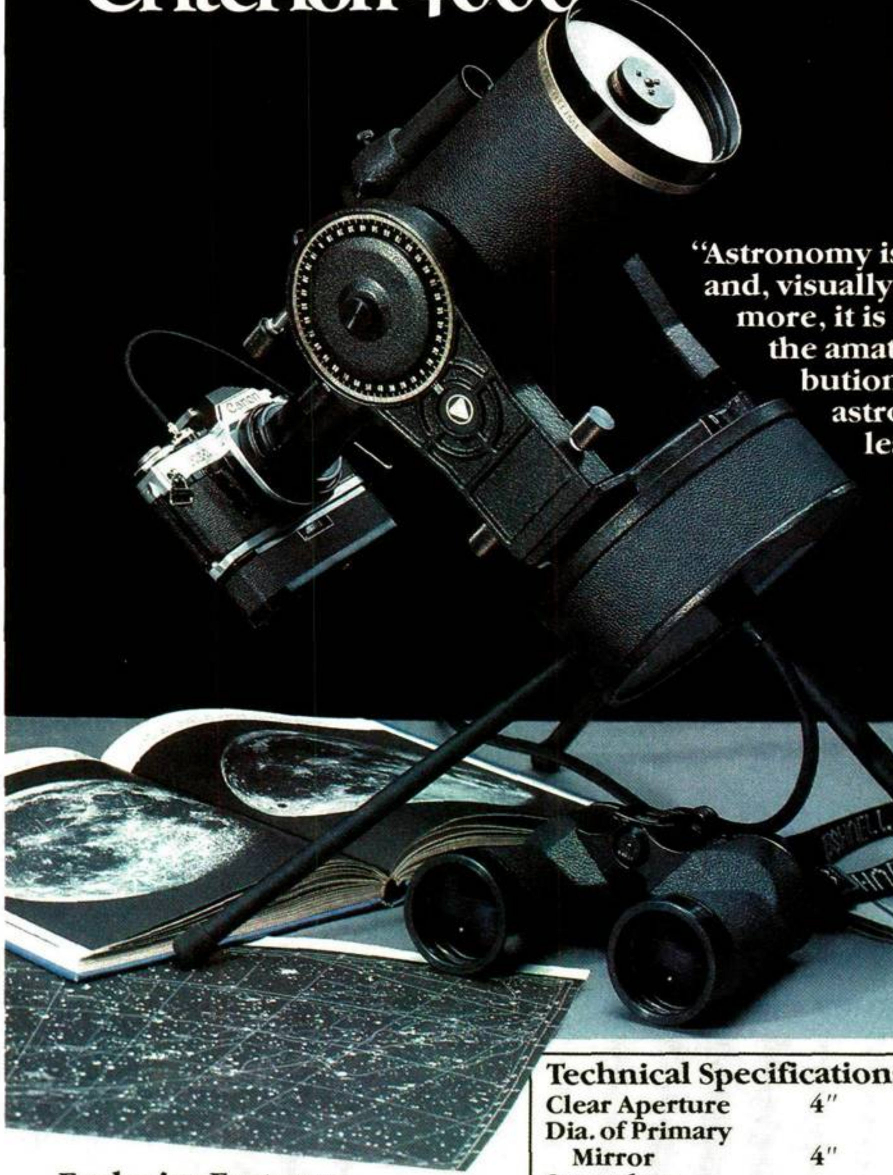

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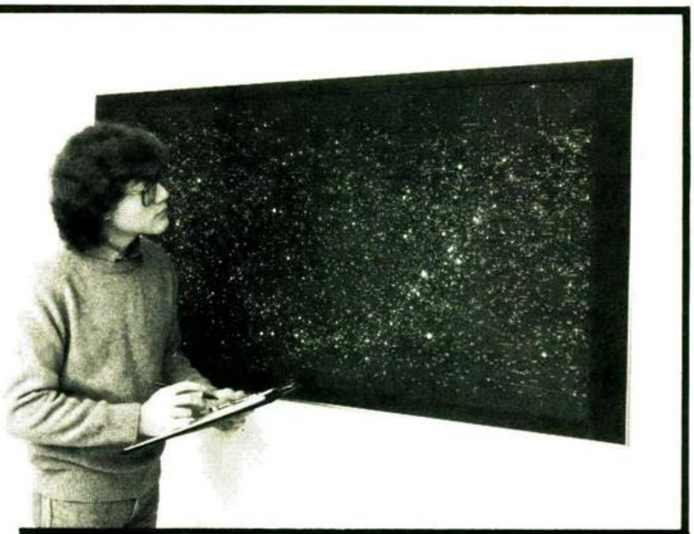

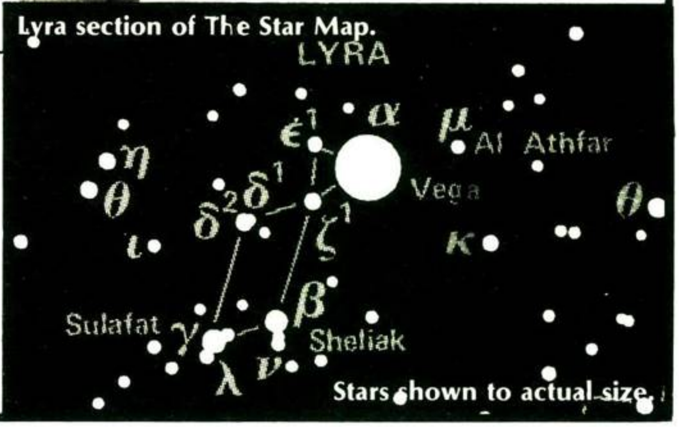

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In Focus

Upright View

Sir / In almost every guidebook or article for the neophyte astronomer, much ink is devoted to explaining field inversion and image reversal in finder telescopes. These greatly complicate matching star charts to the finder field. And, although a star diagonal eliminates the inversion, image reversal remains a property of all refractors with right-angle prism diagonals.

There is a solution to this problem, however — one that is applicable to all refractor, Cassegrainian, and SCT systems. It gives an erect and non-reversed field. Instead of using a right-angle prism or optical flat in the instrument's star diagonal, use an Amici or roof prism instead. This prism gives an image that's both right side up and unreversed, so the stars appear just as they do on star charts.

Such diagonals were available from several sources in the past, and at reasonable prices, too. Today no catalog that I'm aware of offers such diagonals. I feel it's time for commercial production to resume.

Once you've tried an Amici prism star diagonal, you won't want to go back to a plane prism or mirror star diagonal again, at least not for low-power and finder telescope use.

Jessie J. Carroll
Chicago, IL

Starlight Scopes

Sir / In the February In Focus, R.D. Newman of Toronto, Ontario, stated that starlight spotting scopes are available only to the military. True in Canada, perhaps, but not here. Several manufacturers of image intensifiers *sell* to the public, and some have even advertised in ASTRONOMY. I have been using a Litton model 841 miniature night vision scope for several years on my telescope for visual, photographic, and television observing.

I have checked with Litton and found that they are still available for sale to the public. The only restriction is that the buyer agree not to resell the device outside the country without approval from the State Department. Mr. Newman could probably purchase one in Canada, too.

Please note: I am neither an employee of Litton nor a member of the military! In addition to Litton, intensifiers are also manufactured or sold by Amperex, Electrophysics Corp., FJW Industries, ITT, RCA, Varian, and Varo, to name but a few.

Peter L. Manly
Tempe, AZ

Wanted: Better Mountings

Sir / In these days of large aperture mania, it's refreshing to read James Saraceno's tribute (ASTRONOMY Forum, February 1984) to 6-inch f/8 reflectors.

Some of my sharpest views of planets and double stars have come from just such an instrument, combined with a high-quality eyepiece. While today's popular catadioptric telescopes can't be beat for convenience of use, a 6-inch f/8 Newtonian does seem to produce a cleaner, contrastier image.

However, many seem to have one major drawback — equatorial mounts that can detect earthquakes in the mid-Pacific! If only manufacturers would put as much effort into making rock-solid mounts as they do into their $\frac{1}{10}$-wave optics, then the 6-inch f/8 would indeed be "perfect for everything."

Clive Gibbons
Burlington, Ontario

"Unique" Superfinders?

Sir / ASTRONOMY Reviews for January mentions the Lumicon Deluxe Superfinder telescope, and in his review, Robert Allen Buss says that this scope's specifications are unique. That's not quite right — the Unitron 80mm, 500mm focal length is the same. I got it a couple of years ago and it still provides me with great sights at night.

Pat Ryan
West St. Paul, MN

On the Line

Sir / Here in Petersburg, Virginia, we consider ourselves quite lucky. We are right in the center of the three-mile-wide track the eclipse will follow as it passes on May 30, 1984.

Our fine city is located right at the intersection of Interstate 85 and Interstate 95 and is very accessible from all directions. We have an abundance of wide-open areas, which will make it possible to view this annular eclipse at its glorious maximum.

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Petersburg, VA

Comet Con?

Sir / With regard to NASA's plan to send a satellite to a comet in 1985, I see this as nothing more than an attempt by the government to do a con job on the American public. They want us to believe that NASA is launching a major mission to a comet. Since NASA is not sending a spacecraft to Halley's Comet, although the Russians and Europeans and Japanese are, NASA hopes to obscure this fact by sending a second-rate mission to another comet first. The real test of whether or not the American public will buy this will come in 1986.

Larry C. Bender
Enid, OK

— As the U.S. learned from the Russians early in the "space race," being first is quite important.

New Telephone Time Service

Sir / I'd like to make timings of the events during the upcoming annular eclipse. I understand there is a radio station that broadcasts time signals continuously. How do I tune it in?

P.A. Laughlin
New York, NY

The station you refer to is WWV, which is operated by the National Bureau of Standards and broadcasts at the shortwave frequencies of 2.5, 5, 10, 15, and 20 MHz. There is another way to get accurate time signals: by phone. The U.S. Naval Observatory has recently instituted a phone-in time service using the 900 area code. For a cost of 50 cents for the first minute (and 35 cents each minute thereafter), you can receive a time signal determined by the U.S.N.O.'s Master Clock, the official timekeeper for the U.S. The phone number is (900) 410-8463. (As a mnemonic, note that the last four digits spell "TIME.")

The system uses a dedicated landline whose delay (in the contiguous U.S.) is less than 25 milliseconds and which remains constant for any particular location you phone from. Up to 8,000 callers can be served at one time, and you can stay on as long as you care to pay for.

20th Century Mythology

Sir / In response to Carol Rutter's article "Hollywood Astronomy" in the March issue, I agree that there's an appalling lack of accuracy in science fiction films. They certainly didn't *have* to show Han Solo careening through the asteroid belt, or the rotating galaxy at the end of *The Empire Strikes Back*. It sure is strange how the advanced Kryptonians in *Superman* find it so unbelievable that their sun might supernova. Funny how those scientists on the space station in *Star Trek II* send the starship *Reliant* out to find a dead planet for testing — when their station orbits around one. Pretty dumb.

But, then, on the other hand, films like these present young viewers with astounding vistas that speak volumes more than written word or spoken lecture or cold mathematics.

Star Wars and *Star Trek* are 20th century mythology. Before you dismiss that mythology with disdain, remember that we still learn astronomy by first memorizing the ancient mythological constellations. So too can these modern fantasies excite us and our children about space.

Kubrick, Lucas, and Roddenberry have done as much to popularize the cosmos as have Sagan, Asimov, and Jastrow. We are in their debt.

James Scott Hicks
Gibbes Planetarium
Columbia, SC

IRAS Corrections

Sir / Two corrections to Robert Burnham's fine article "IRAS: The Infrared Universe" (ASTRONOMY, March issue), plus a comment.

The average asteroid orbit isn't inclined anything like 30° to the ecliptic plane. The median asteroid-orbit inclination (C.W. Allen, *Astrophysical Quantities*) is just 8.6° — i.e., essentially that of the IRAS-discovered dust bands above and below the ecliptic.

Second, Comet IRAS-Araki-Alcock wasn't the first comet in history discovered by a spacecraft. That honor belongs to Comet Howard-Koomen-Michels, which hit the Sun on August 30th, 1979, and was discovered years later in analysis of the SOLWIND pictures — as ASTRONOMY reported in AstroNews for January 1982.

What IRAS-Araki-Alcock does have is the dubious honor of being the first comet named for its *instrument of discovery* rather than its discoverer. Does this now mean that if I discover a comet next year using a Celestron, I must suffer seeing it named Comet Celestron instead of Comet Loudon? Or suppose I used a homemade telescope — would it become Comet Homemade?

Jim Loudon
Exhibit Museum
University of Michigan
Ann Arbor, MI

Ooops!

The photo on page 60 of the April issue should be credited to James Janesick, and that on page 19 of the January issue should be Royal Observatory, Edinburgh.

Behind the Scenes

Dark Skies for Comet Halley

When Comet Halley swung past Earth in 1910, America was a patchwork of farms, small towns, and villages; only a few bright lights pierced the night. For most people, the stars were the only lights at night. When Halley flew by — its long tail stretched across the skies — anyone who looked for it, saw it.

In 1985/86, Halley will swing past a very different Earth. Most city-dwellers never see the stars, their eyes dazzled instead by the glare of street lamps, yard lights, and neon. And when they suddenly decide they want to see Comet Halley, they probably won't be able to.

It sounds pretty bad. Well, somebody's doing something about it. ASTRONOMY Eye on the Sky columnist Fred Schaaf has founded Dark Skies for Comet Halley, an organization to work for dark skies for Comet Halley. The idea is simple: to persuade municipalities to shut off all unessential lights for a few nights when Comet Halley will be most visible.

Fred has pursued DSCH with tremendous diligence — you may have seen his first letter in *Science 82* — and continues to do so. Now, to bind DSCH together and promote the interchange of information between its members, in cooperation with the Astronomical League, he has launched the *Dark Skies for Comet Halley Journal*.

You can be involved in putting out the lights for Comet Halley. If you, too, are concerned about the thousands of youngsters who will *NOT* see the comet this time around *unless you do something about it*, then I urge you to join DSCH and receive the four-page quarterly *DSCH Journal*. It is modestly priced at $4 per year in the U.S. and $5 per year if you live outside the U.S. The address is:

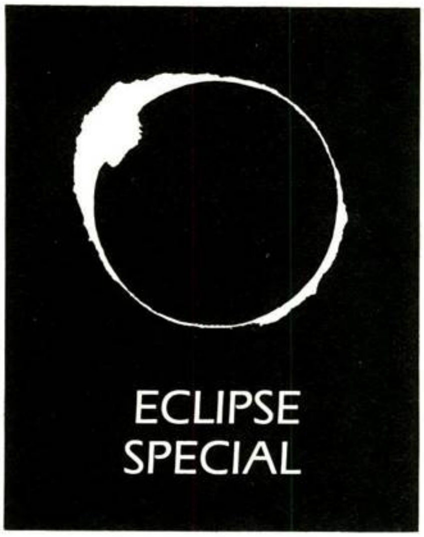
DSCH Journal
RD #2, Box 248
Millville, NJ 08332

Don't think that DSCH will be an easy job. It's going to be difficult to convince legislators in hundreds of cities and towns to shut down inefficient outdoor lighting for even one night. But it's worth a try!

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief



The Great Annular Eclipse of 1984

by
Fred Espenak

On Wednesday morning, May 30, 1984, North Americans will be treated to a very unusual annular eclipse of the Sun. The annular phase will be visible in a narrow belt that runs from the Pacific Ocean through central Mexico and the southeastern United States, across the North Atlantic, and terminates in North Africa. A partial eclipse will be seen over most of North America (excluding Alaska), the northern tip of South America, western Europe, and North Africa.

The last time that a heavily populated region of the United States fell within the path of an eclipse was in February 1979. The next opportunity will not occur for almost exactly a decade — until May 10, 1994. (See "North American Solar Eclipses: The Next 50 Years," ASTRONOMY, November 1980.)

An annular eclipse differs from a total one in that instead of totally covering the bright photosphere of the Sun, the Moon — which appears smaller than the Sun — leaves a blindingly bright ring, or *annulus*, of Sun uncovered. Because of this, the Sun's pearly-white corona — the "star attraction" of a total eclipse — is absent at annular eclipses.

But this May's event is remarkable in that it is neither exactly annular nor completely total. Instead of a continuous unbroken ring of Sun, the Moon will be surrounded by a dazzling string of "beads" and short crescent arcs. The arcs are created when tall lunar mountains and highland areas extend beyond the Sun's limb; the beads form when rays of sunlight shine through deep valleys along the Moon's limb. The effect was first noted by the English astronomer Francis Baily during an annular eclipse in 1836, and they are still known as "Baily's beads." Together, Baily's beads and the broken crescents surrounding the Moon will give the appearance of a sparkling diamond necklace. The effect, lasting for 10 to 20 seconds, can be seen only from the very narrow path of annularity.

The Path of Annularity

The Moon's umbral shadow has the shape of a cone and stretches 228,260 to 236,120 miles, its exact length varying with the Moon's distance from the Sun. During a total eclipse, the shadow touches the Earth and sweeps across its surface, defining a path of totality. When the umbra is too short to reach the Earth, an annular eclipse results. In this case, we can imagine a "negative shadow" or *anti-umbra*, as the mirror image of the umbra, beginning at the umbral vertex and extending out to infinity. The ground track of the anti-umbra traces out a "path of annularity" along which an annular eclipse is visible.

The May 30 eclipse begins at 14:57 UT (Universal Time) when the Moon's anti-umbra first touches down at local sunrise near the equator about 4,100 miles west of Equador. The shadow moves swiftly here because its motion runs at right angles to the counteracting effects of the Earth's rotation. Traveling about 5000 miles an hour, the anti-umbra quickly reaches the western shore of Mexico at 15:26 UT. The path is 17 miles wide and annularity lasts 35 seconds during the early morning. It's interesting that the eclipse in Mexico is truly annular. Observers there are far enough away from the Moon so that even its tallest mountains appear to fall short of the Sun's limb. Later on, the bulge of the Earth will bring U.S. observers closer to the Moon, and they'll witness the "diamond necklace" phase.

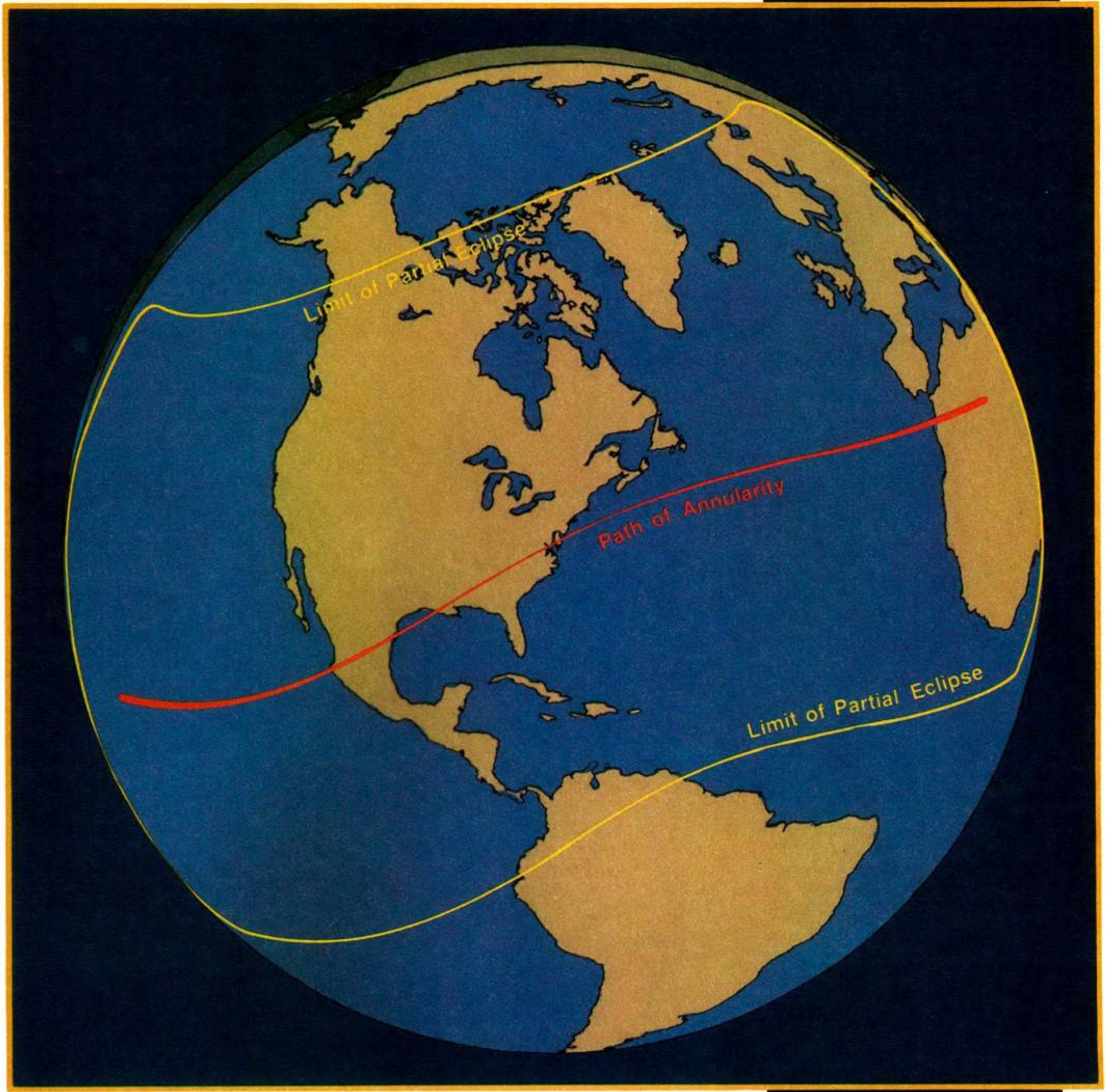
As the shadow sweeps across central Mexico, it will engulf the cities of Guadalajara, San Luis Potosi, and Ciudad Victoria. Here the ring of sunlight around the Moon will have an average thickness of only 6 arc-seconds. The anti-umbra reaches the eastern coast of Mexico at 15:44 UT, about 60 miles south of Brownsville, Texas. As it crosses the Gulf of Mexico, its velocity continues to slacken, the path grows narrower, and the duration of annularity decreases.

The anti-umbra arrives at the southern coast of the U.S. at 16:01 UT, entering Louisiana by way of Atchafalaya Bay. The path width has shrunk to under 9 miles and the annular phase now lasts 20 seconds. An observer on the center line may see the annular ring broken by lunar mountains at one or two points along its southern edge. Traveling at 1,550 mph, the shadow passes 15 miles north of New Orleans, where a partial eclipse of magnitude 0.991 will be seen.

After crossing Lake Pontchartrain, the anti-umbra enters Mississippi at 16:07 UT. Somewhere near the Mississippi-Alabama border, the umbra's vertex swings close enough to Earth for several lunar mountains along the Moon's southern limb to appear to extend beyond the edge of the Sun. Center line observers will see an exceedingly thin annulus only 3 arc-seconds wide with several tiny breaks along its southern edge. Passing 15 miles north of Montgomery, Alabama, at 16:16 UT, the shadow continues on its northeastern course.

In Georgia, the 6-mile-wide path sweeps directly across Atlanta at 16:23 UT. Here the annular phase lasts 14 seconds, but "duration" takes on a rather academic meaning. Most duration predictions assume the Moon's limb is perfectly smooth. In fact, the rugged lunar topography causes the Moon's limb to depart from a perfect circle by 3 or 4 seconds of arc. As a result, the period of maximum eclipse will be chaotic: Baily's beads, short arcs, and broken crescents will all appear rapidly, rotate around the Moon's limb, and disappear. Most of the activity will happen within a minute of maximum eclipse, but some events could occur as much as 5 to 10 minutes before or after, depending on your position relative to the center line.

As the shadow enters South Carolina, its velocity decreases to a "leisurely" 1,400 mph. The center line runs through Greenville, where maximum eclipse occurs at 16:29 UT. Here the annulus will have an average thickness of 2 seconds of arc, but it will be broken by lunar mountains at over a dozen points. The path continues through North Carolina, where it passes between Winston-Salem



With its path of annularity passing across the southeastern United States, the May 30th solar eclipse will be visible over almost all of North America — either as annular (along the red line) or as partial (inside the yellow line). All diagrams based on those of the author.

and Greensboro at 16:35 UT. Each city witnesses a partial eclipse with a magnitude of 0.995 or more.

The local apparent solar time is almost noon as the anti-umbra enters Virginia. The path runs through Petersburg, where maximum eclipse occurs at 16:43 UT. Richmond, with an eclipse magnitude of 0.989, lies 25 miles to the north of the path. Two minutes later (16:45 UT), greatest eclipse occurs just as the shadow crosses the York River (latitude = 37° 29′ N, longitude = 76° 44′ W). At this instant, the axis of the Moon's shadow makes its closest approach to the center of the Earth; the vertex of the umbra is only 470 miles overhead. This is where the Moon subtends its largest angular diameter and the eclipse attains its greatest magnitude: 0.9980.

The duration of annularity on the center line is now at a minimum (11 seconds), and the eclipse path is only 4.5 miles wide. Along the Virginia section of the path, the beading events and "diamond necklace" effect will be most spectacular. The average thickness of the segmented annulus is expected to be less than 2 arc-seconds. Traveling at 1,360 mph, the umbra crosses Chesapeake Bay in two

Path of Annularity

Longitude	Northern Limit Latitude	Center Line Latitude	Southern Limit Latitude	Path Width	Center Line Duration	Center Line Mid-eclipse
94°0′ W	27°36.0′ N	27°30.4′ N	27°24.9′ N	9.90 mi	22.0 sec	15:54:17 UT
93 30	27 57.5	27 52.2	27 46.8	9.59	21.5	15:55:45
93 0	28 18.9	28 13.7	28 8.5	9.29	20.9	15:57:14
92 30	28 40.1	28 35.1	28 30.0	9.00	20.4	15:58:42
92 0	29 1.1	28 56.2	28 51.4	8.73	19.9	16: 0:11
91 30	29 21.9	29 17.2	29 12.5	8.46	19.4	16: 1:41
91 0	29 42.5	29 37.9	29 33.4	8.20	18.9	16: 3:11
90 30	30 2.8	29 58.4	29 54.0	7.95	18.4	16: 4:41
90 0	30 22.9	30 18.7	30 14.4	7.71	18.0	16: 6:11
89 30	30 42.8	30 38.7	30 34.6	7.48	17.5	16: 7:41
89 0	31 2.4	30 58.4	30 54.4	7.26	17.1	16: 9:12
88 30	31 21.7	31 17.9	31 14.1	7.04	16.7	16:10:42
88 0	31 40.8	31 37.1	31 33.4	6.84	16.3	16:12:13
87 30	31 59.6	31 56 0	31 52.4	6.65	15.9	16:13:43
87 0	32 18.1	32 14.7	32 11.2	6.46	15.5	16:15:13
86 30	32 36.4	32 33.0	32 29.6	6.29	15.2	16:16:43
86 0	32 54.3	32 51.1	32 47.8	6.12	14.8	16:18:13
85 30	33 12.0	33 8.8	33 5.6	5.97	14.5	16:19:43
85 0	33 29.3	33 26.3	33 23.2	5.82	14.2	16:21:12
84 30	33 46.4	33 43.4	33 40.4	5.68	13.9	16:22:41
84 0	34 3.1	34 0.2	33 57.3	5.55	13.6	16:24:10
83 30	34 19.6	13 16.7	34 13.9	5.42	13.4	16:25:39
83 0	34 35.7	34 33.0	34 30.2	5.31	13.1	16:27: 7
82 30	34 51.1	34 48.8	34 46.2	5.20	12.9	16:28:35
82 0	35 7.0	35 4.4	35 1.8	5.10	12.7	16:30: 2
81 30	35 22.2	35 19.7	35 17.1	5.01	12.5	16:31:29
81 0	35 37.1	35 34.6	35 32.1	4.92	12.3	16:32:55
80 30	35 51.7	35 49.2	35 46.8	4.85	12.2	16:34:21
80 0	36 5.9	36 3.5	36 1.1	4.78	12.0	16:35:46
79 30	36 19.9	36 17.5	36 15.2	4.79	11.9	16:37:11
79 0	36 33.5	36 31.2	36 28.9	4.66	11.8	16:38:35
78 30	36 46.9	36 44.6	36 42.3	4.61	11.7	16:39:59
78 0	36 59.9	36 57.6	36 55.4	4.56	11.6	16:41:22
77 30	37 12.6	37 10.4	37 8.2	4.53	11.5	16:42:45
77 0	37 25.0	37 22.8	37 20.6	4.50	11.4	16:44: 7
76 30	37 37.1	37 34.9	37 32.8	4.47	11.4	16:45:28
76 0	37 48.9	37 46.8	37 44.6	4.45	11.3	16:46:49
75 30	38 0.4	37 58.3	37 56.1	4.44	11.3	16:48: 9
75 0	38 11.6	38 9.5	38 7.4	4.43	11.3	16:49:29

minutes and quickly traverses the Delmarva Peninsula. The shadow leaves the United States at 16:49 UT as it cuts across Assateague Island, Maryland, and heads out to sea.

During the next 85 minutes, the anti-umbra sweeps over 2,500 miles of North Atlantic with no landfall. Finally, the shadow reaches the Azores, where two of the northern-most islands stand in its path. By this time, however, the planet has curved away from the vertex of the umbra far enough that no lunar mountains will appear to break across the ring of Sun — a true annular eclipse is seen once again. Residents of Santa Cruz, Graciosa, will witness a 38-second annular phase at 18:14 UT. The Sun will be 31° above the western horizon during the late afternoon event. The northern shore of Terceira also lies within the 20-mile-wide path, which now runs east-southeast.

Fifteen minutes later (18:29 UT), the shadow reaches the coast of Morocco. Famed Casablanca lies north of the path and experiences a partial eclipse of magnitude 0.969 shortly before sunset. Quickly traveling inland, the anti-umbra leaves the Earth in central Algeria, where the annular eclipse ends at 18:33 UT.

Plotting the Path

Since the U.S. section of the path of annularity is only 4.5 to 9 miles wide, it's very important to have an accurate map if you wish to observe the dramatic "diamond necklace" phase. The road map in the family car might be good enough — but why take chances? The U.S. Geological Survey (USGS) publishes a series of topographic maps covering the entire country; those on the 1:250,000 series are excellent. First, you'll need to decide where you want to observe the eclipse. (Use the map of the eastern U.S. on the opposite page to start with.) Keep in mind that the stretch through Virginia promises the most spectacular views.

The next step is to check your Yellow Pages under "Maps" to find out where the nearest USGS map distribution center or map store is. Bring your rough eclipse map to the store to help you choose the proper 1:250,000 series map. If your planned site lies near a map boundary, buy the adjoining map also — they're only $3.60 each. Also pick up a free USGS map index for your state.

If you can't buy the map you need locally, you can order maps directly from the USGS by writing the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202. But don't dawdle! Mail orders to the USGS can take several weeks to process, and a map that arrives after May 30 won't be very much help. If time's running out and you're getting desperate, try a large public or university library. They often have good map collections (the university's geography department is another possibility), and a few minutes spent at the photocopier with some pocket change will get you something to use in a pinch.

With map in hand, you're ready to make an accurate plot of the path of annularity. Take the positions listed in the table at left and plot the northern and southern limits and the center line. At the scale of your map, the curve of the path is negligible, so use a straight line to connect adjacent coordinates. To avoid confusion and plotting errors, plot all the northern limits first. Then plot the southern limit coordinates, checking that they run parallel to the northern limit. Finally, plot the center line in a different color.

For information on what equipment to use in observing and photographing the eclipse, see "How to Observe and Photograph the Annular Solar Eclipse," beginning on page 50.

The "Diamond Necklace"

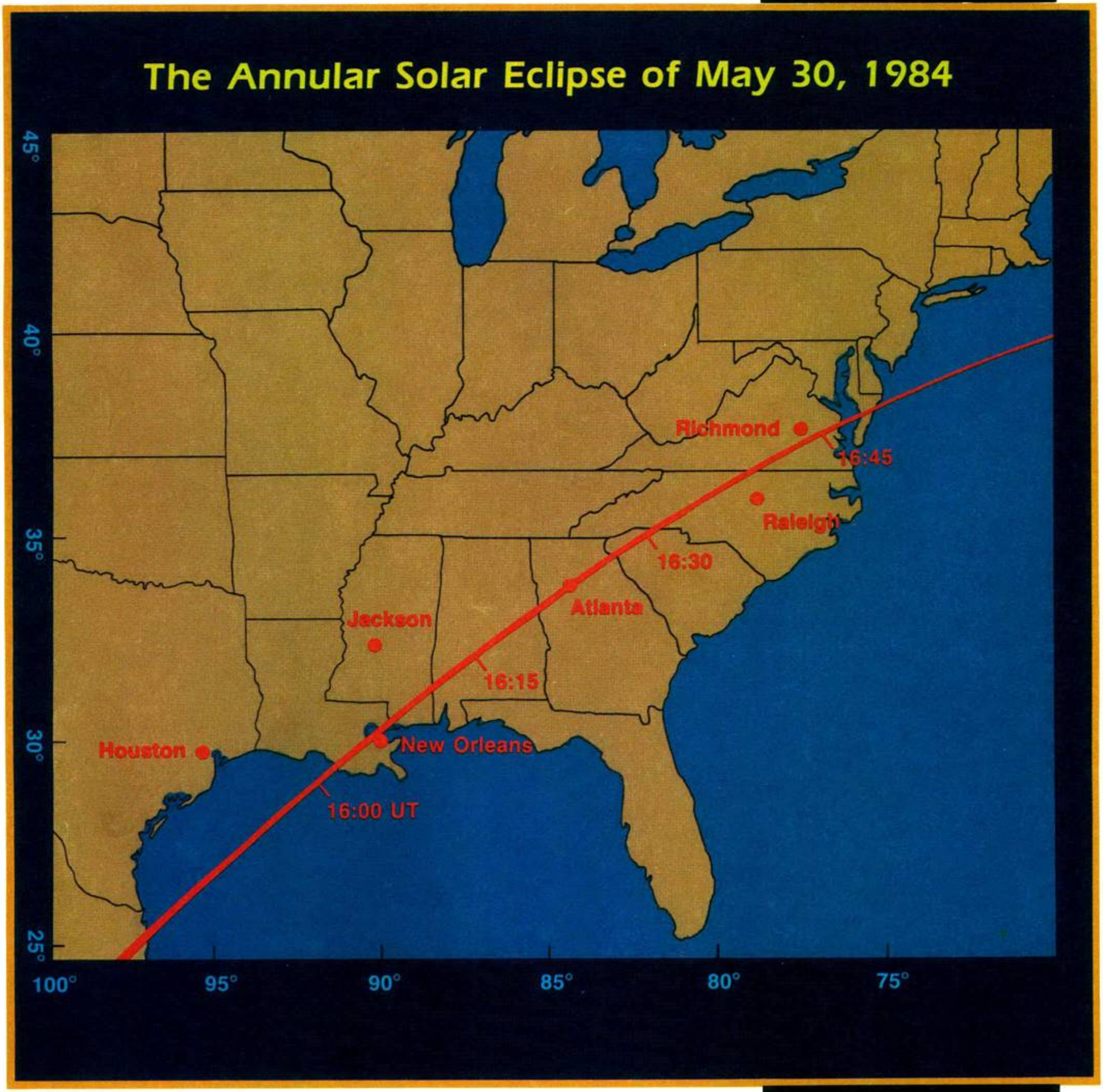
The "diamond necklace" will be the main event for most observers who journey to the path of annularity. But predicting exactly what it will look like is difficult. To begin with, it calls for very thorough knowledge of the Moon's limb profile. The current model uses the catalog compiled about 25 years ago by astronomer Chester Watts of the U.S. Naval Observatory. The diagram on page 38 shows the predicted lunar profile for an observer in the annular path from eastern Virginia. It exaggerates the radial scale 67 times in order to make the lunar topography more apparent.

In Virginia, the Sun's limb exceeds the Moon's mean limb by only 1.8 arc-seconds. Wherever a lunar feature extends beyond the Sun's limb, the annular ring will appear broken. The topography of the Moon's southern highlands is so rugged that it interrupts the Sun's limb at many points and should produce numerous beads during maximum eclipse. The arrow running through the center of the diagram shows how the Moon will be moving with respect to the Sun. During the eclipse, the Moon will appear to gain on the Sun at 0.33 arc-second per second.

Will the Corona Be Visible?

A heated debate has been going on among observers for some time over whether or not the corona will be visible at this eclipse. The chances are you won't be able to see it — but let's take a look at what past experience has to say.

Since the annular eclipse of May 20, 1966, is the immediate predecessor of the 1984 event in its saros series, they share many similarities. Eyewitness accounts from 1966 may give a preview of what's in store this month. In 1966, the path of annularity ran from the mid-Atlantic through North Africa, Greece, Turkey, the Black Sea, and across southern Siberia. During the eclipse, the Sun's diameter was less than 1 arc-second greater than the Moon's, and the maximum phase lasted only a second or so. Clearly, the 1966 event was even closer to being total than



The Annular Solar Eclipse of May 30, 1984

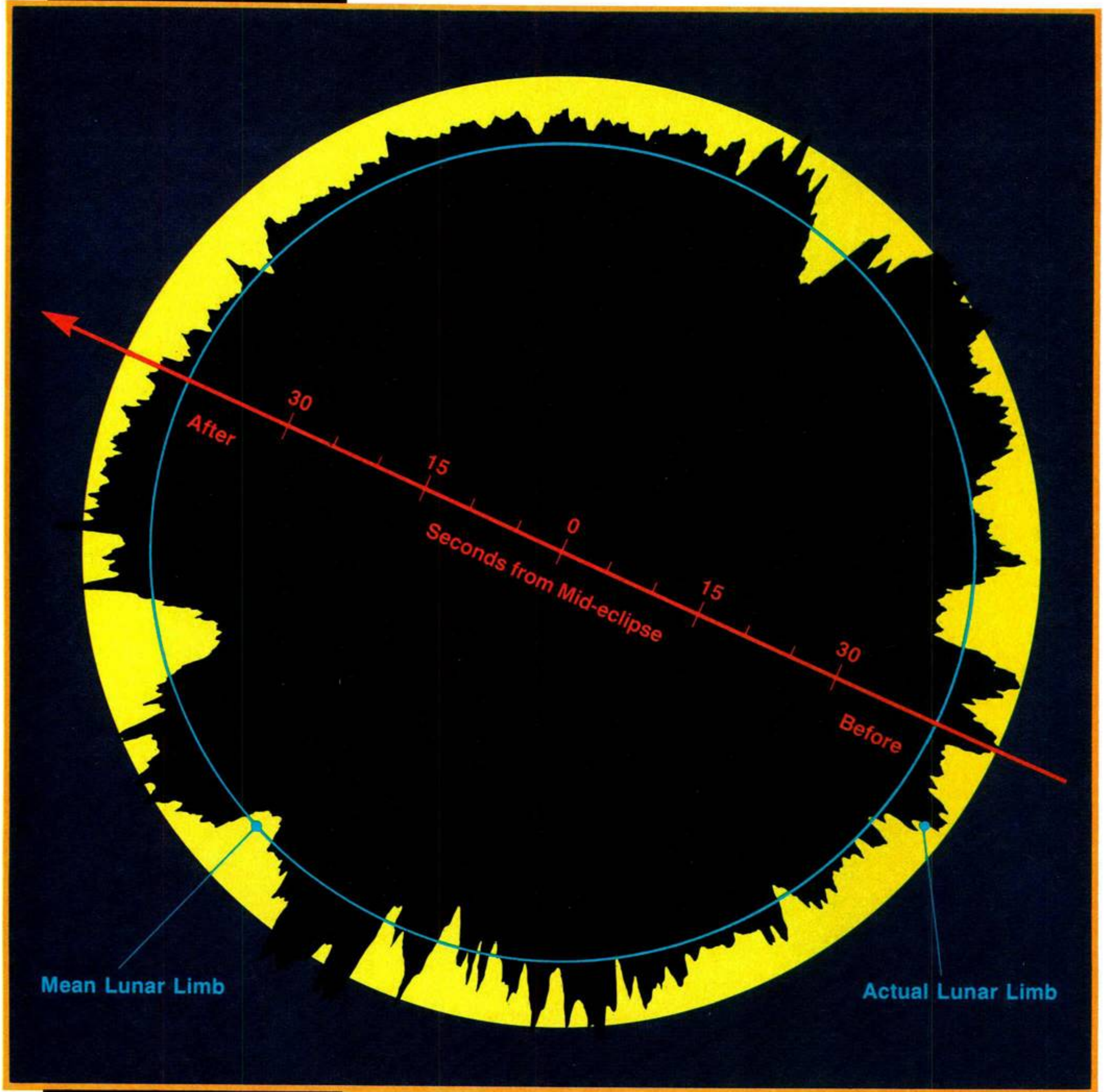
Although the path of annularity passes conveniently over Atlanta, Georgia, the best views will probably be at sites along the path in Virginia. The tick marks on the path indicate the times of mid-eclipse and are in Universal Time — subtract 4 hours to get EDT, 5 hours for CDT.

this year's will be.

Stationed southeast of Athens, astronomer Donald Menzel said, "The crescent suddenly begins to break into dozens of beads where the bright Sun shines through lunar valleys. The Sun looks like a diamond necklace, but a moment later the annular stage is over, almost before it began. I could not glimpse the solar corona because the beads were too dazzling."

Another expert, M. Waldmeier of the Swiss Federal Observatory was in western Turkey near the point of greatest eclipse. He made measurements under a very clear sky with the Sun 69° above the horizon. "The crescent along the east limb of the Sun broke into several isolated sections, and almost simultaneously Baily's beads became visible along the west limb, too. For about one second, the black Moon was completely surrounded by a circle of 'diamonds.' The Sun was never completely masked, but at no moment was its bright ring uninterrupted."

The Sun's faint outer atmosphere, or corona, is usually only seen during total eclipses. At annular eclipses, the ring of sunlight surrounding the Moon is so bright



The jagged black circle is the actual profile of the Moon, with its topography exaggerated for clarity. In many places the ring of sunlight (yellow) will be broken by lunar mountains. The scale indicates where the center of the Moon will be at various times relative to mid-eclipse and shows its direction of movement.

that it floods the sky with light and eliminates any possibility of seeing the corona. Although Waldmeier's report made no mention of detecting the corona visually, he *was* successful in photographing the innermost parts of it: "Just before central eclipse, the Sun's thin eastern crescent was masked by an occulting screen like that used in a coronagraph, permitting photography of the inner corona adjoining the west limb of the Moon. In a similar manner, the eastern part of the inner corona could be recorded immediately after central eclipse."

He was also able to observe the chromosphere although it did not contain any especially large or bright prominences. "This crimson border became simultaneously visible along half of the Sun's circumference. First it appeared for a few seconds on the west side, then vanished for about three seconds at mid-eclipse when the photospheric ring was too bright, and finally appeared again along the east limb."

The solar corona can be seen briefly both before and after a total eclipse during the "diamond ring" phase. At this time, a narrow crescent of direct sunlight is visible as a blazing jewel along one edge of the Moon, while the fainter corona encircles the rest. The corona is typically 1/10,000,000 as bright as the Sun's disk and a tenth as bright as a pure blue sky under ideal conditions.

It's difficult to observe a faint object adjacent to a bright one, and it's also hard to see one that is barely brighter than its background. The Sun's bright limb may be occulted by artificial means, but the ultimate constraint limiting the corona's visibility lies in the sky brightness. This is determined by the sky's transparency and by how much sunlight is scattered off dust particles in our atmosphere.

On February 26, 1979, I observed a total solar eclipse from Riverton, Manitoba. I first detected the corona during the "diamond ring" phase, 10 seconds before the start of totality. However, in 1979 the Moon's shadow was a huge ellipse measuring 83 by 1,910 miles, and this helped darken the sky a lot. Also, in 1979 the Sun was near sunspot maximum, which means the corona was at its brightest. The 1984 eclipse occurs near sunspot *minimum* — and the corona is expected to be only half as bright. On the other hand, the sky conditions will be better this year and the Sun will be higher.

I repeated my attempt to observe the corona outside totality during the June 11, 1983, eclipse. My observing site was 15 miles southeast of the center line in central Java, and totality lasted almost five minutes. About 30% of the sky was filled with scattered clouds, but the Sun was in a large clear hole where the transparency was excellent. I was observing through the viewfinder of a camera attached to a 1000mm f/11 Maksutov telescope. I saw the corona and photographed it 20 seconds before totality began, but it may have been visible earlier.

After totality ended, I continued to observe and photograph the corona for another 51 seconds. Although the exposed solar crescent was dangerously bright, I was able to move it out of my line of sight by placing my eye off axis and about two inches behind the camera eyepiece. (Unfortunately, further observations were not possible due to the commencement of post-totality celebrations!) But this observation remains the best evidence that the corona may be seen in 1984.

Actually, you've got a much better chance with the solar chromosphere and prominences along the Sun's limb. The chromosphere is a thin layer of gas that lies between the Sun's bright surface or photosphere and the very faint solar corona. The chromosphere (and prominences) glow in hydrogen's characteristic red color and can usually be seen for several seconds as totality begins and ends. During May's eclipse, the best place to see the chromosphere is along the western limb just before annularity begins and along the eastern limb just after it ends. During the "diamond necklace" phase, Baily's beads and the broken annulus of Sun will be too bright and will probably drown out the chromosphere and prominences.

But note this well: any attempt to observe the corona, chromosphere, and prominences directly places your eyesight in considerable danger. Even the briefest glance at the thin solar crescent, the "diamond necklace" phase, or annularity can result in serious eye damage and permanent blindness. All stages of the eclipse should be viewed through a solar filter specifically designed for that purpose. Visual searching for the corona, chromosphere, and prominences should be undertaken by experienced eclipse observers *only*.

Probably the best method of detecting it is photographic, anyway. Use a solar filter to point your camera at the Sun. About 30 seconds before maximum eclipse, remove the filter — but do not look through the camera! Shoot as many pictures as you can at your highest shutter speeds and replace the filter when annularity begins. You can try it again for 10 to 20 seconds after annularity ends. During this short period, the Sun won't move very far and you shouldn't need to realign your camera. (Direct sunlight may damage your camera's light meter — check your owner's manual before trying this.)

By far, the safest and easiest way to watch or photograph the eclipse is to use a solar filter or optical projection.

Other Observing Projects

By timing Baily's bead events, you can make a valuable contribution to research into the Moon's orbit and the possible variability of the Sun's radius. The chief difficulty in such observations is the fact that the beading events will be numerous and will occur in rapid succession. Even experienced graze occultation observers should expect problems in keeping up with all the action! The best approach is to set up a telescope for optical projection and photograph the projection screen using a sound Super 8 or video camera. If you have a shortwave radio nearby tuned to WWV's time signals, you can record the image and time on your camera's sound track. Finally, you must know your geographic position very accurately if your observations are to be of any value.

Large scale maps like the 7½-minute quadrangle series (1:24,000 scale) from the USGS will allow you to pinpoint your coordinates using buildings, roads, and other landmarks. The USGS state map index you picked up will help you select the appropriate quadrangles. (They cost $2.25 each.) If you wish to participate in such observations, get in touch with the International Occultation Timing Association (IOTA) by writing to Box 3392, Columbus, Ohio 43210-0392.

Observers within 100 miles of the path of annularity will probably notice the sky growing darker around maximum eclipse. Although it won't be as awesome as the eerie twilight you see at a total eclipse, the sky should be dark enough to reveal Venus. Look for it at magnitude −3.4 about 4° west of the Sun. Use your hand to block the Sun and search the sky nearby. If the sky transparency is good, Venus may be visible up to 20 minutes before and after annularity.

Shadow bands are a pleasingly bizarre phenomenon sometimes seen at total and nearly-total eclipses. Several minutes before and after totality, these ghostly mottlings of light and dark ripple across the ground like refraction patterns on the bottom of a swimming pool. They're probably caused by the same atmospheric turbulence that makes stars appear to twinkle.

The bands actually look more like irregular, elongated patches rather than the evenly spaced stripes their name implies. They move at several feet per second and are constantly undulating and changing shape. Photographing them is a real challenge because of their low contrast and rapid motion. But don't be too disappointed if the bands never make their appearance. They're very unpredictable and are only seen when the sky is clear and cloud-free.

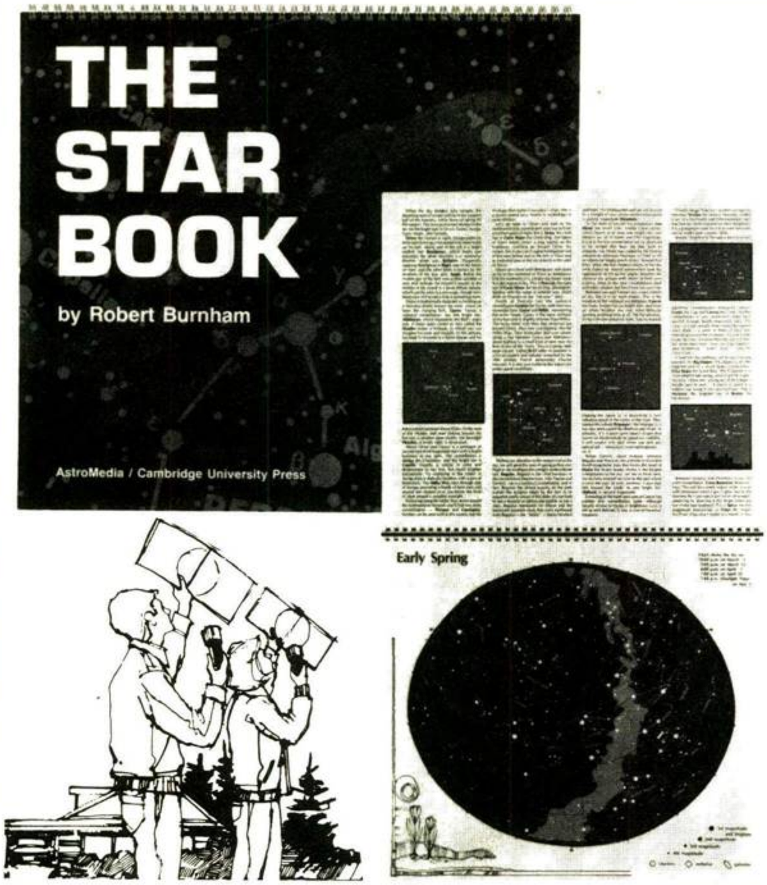
Be on the lookout for another delightfully curious effect which occurs at all solar eclipses. Study the ground under a nearby shade tree while the eclipse is in progress. You'll notice that the small spots of sunlight that filter down between the tree's leaves each mimic the current phase of the eclipse! The gaps between the leaves act like pinhole cameras and each projects its own tiny image of the Sun. You can duplicate the effect yourself by forming a small aperture with your hands and watching the ground below. This effect becomes more prominent as the eclipse deepens.

* * *

These days, it's hard to feel the paralyzing terror early mankind must have felt during a solar eclipse. (*"A demon is devouring our Sun!!"*) We see ourselves as much more sophisticated and largely, if not entirely free of ancient superstition. After all, solar eclipses are simply a direct consequence of geometry and the laws of celestial mechanics. And yet, and yet — this event will still invoke a deep sense of awe. If you've never seen a eclipse from the central path, it's impossible to explain why it's so incredibly striking. You just have to go and see for yourself.

No matter where you are on May 30th, you can be sure that *I'll* be in the path when the demon eats the Sun — and maybe I'll see you there, too.

Fred Espenak is an infrared astronomer at NASA/Goddard Space Flight Center in Greenbelt, Maryland. In his spare time, he travels around the world chasing and photographing eclipses.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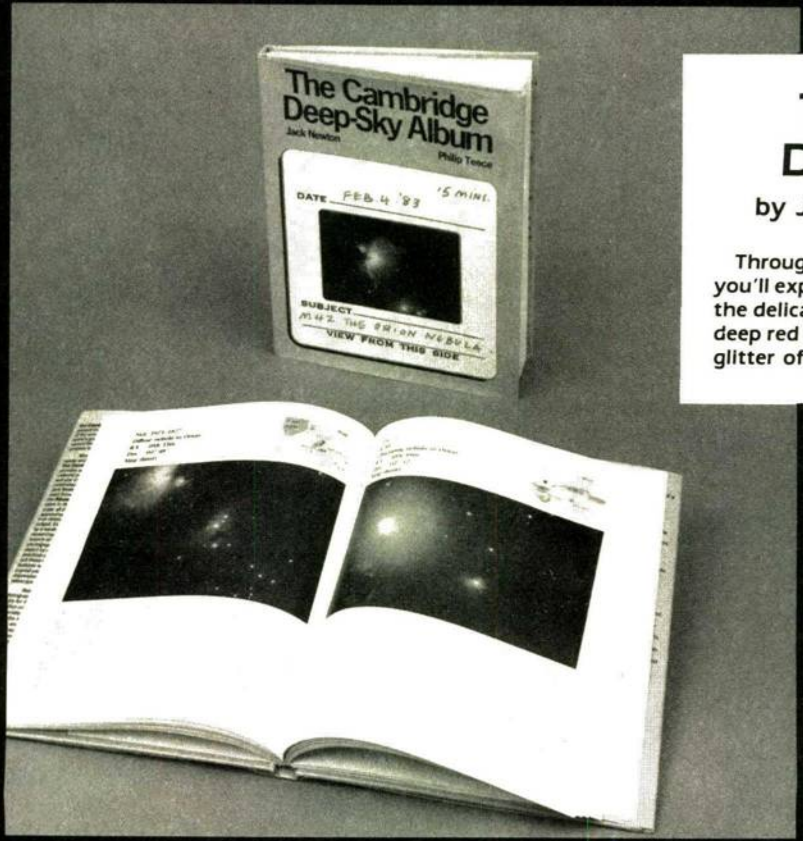
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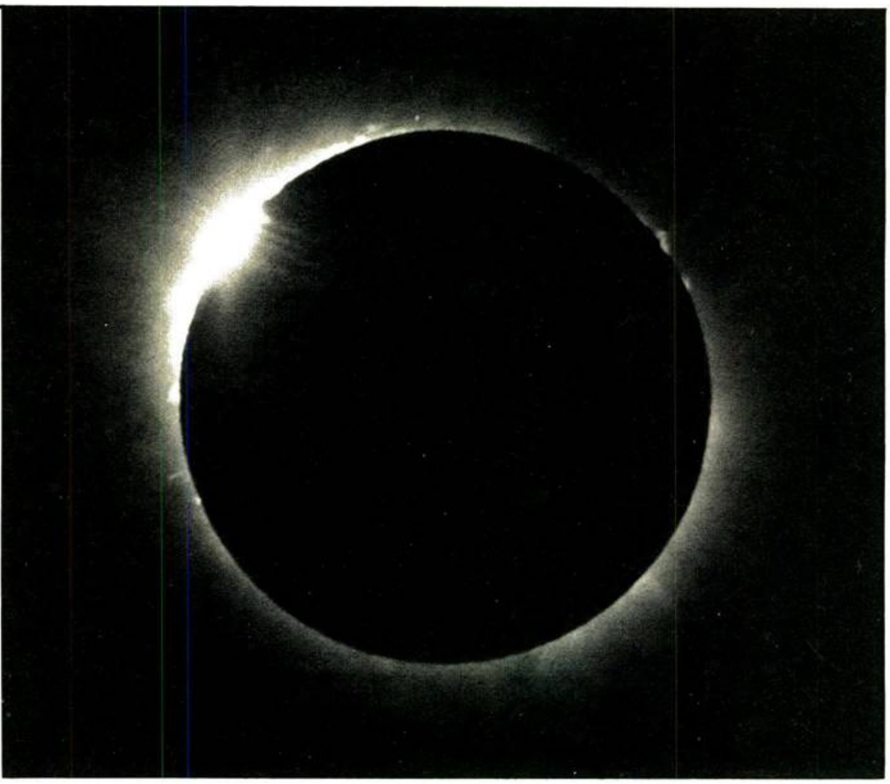
Mars Gleams at Opposition

by
Fred Schaaf



During the total eclipse of 1979, the Moon completely covered the brilliant solar surface, revealing pink prominences in the Sun's chromosphere and the faint, milky glow of its corona. While there's a chance of seeing prominences during the annular eclipse on May 30, the Sun's corona probably won't be visible. Photo by Raynard Bagdis.

Snaking through the heavens like some mythical dragon, a brilliant auroral curtain envelops the stars from Cassiopeia to Ursa Major in its delicate folds. Cascades of electrons create the wispy, rapidly changing form of an aurora. Photo by Daniel Marcus.

The Wanderers

This May is a month of solar system riches for everyone, and especially for observers in the Americas. We'll get two eclipses, as well as two fine oppositions and an important meteor shower related to Halley's Comet. Of these prospects, the most spectacular is certainly the May 30th **annular eclipse of the Sun**.

As explained elsewhere in this issue, the eclipse might best be described as transitional between annular and annular-total. Follow the safe techniques we suggest if you're in that narrow corridor across the southeast United States in which a few seconds of flaring arcs and Baily's beads will form a broken ring of fire at midday.

The rest of the eastern United States and Canada will be treated to a very deep partial eclipse — the best for decades, in many areas. Wherever the Sun becomes more than about three-quarters covered, the landscape and sky will appear obviously darkened. Shadows will be distorted, and patches of light in the shade of trees will take on roughly crescent forms (chinks between leaves act as "pinhole cameras," forming countless images of the partially eclipsed Sun). At least a slight partial eclipse will occur for almost all of North America except Alaska. (For more on the eclipse phases at various locations, see Gazer's Gazette, page 34.)

May's other eclipse, the first of three in the current eclipse season, is an event of only mild interest. This **penumbral eclipse of the Moon** takes place on the night of May 14-15 for the Americas. At 12:40 a.m. EDT on the 15th (9:40 p.m. PDT on the 14th), the penumbra extends northward across 83 percent of the Moon's diameter — but only the deeper penumbra on the southern edge of the Moon will be detectable as a slight darkening. This will be the last lunar eclipse of any kind visible from the Americas until 1986. Many of us will have to wait even longer to see the shadow of Earth on the Moon's face again.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

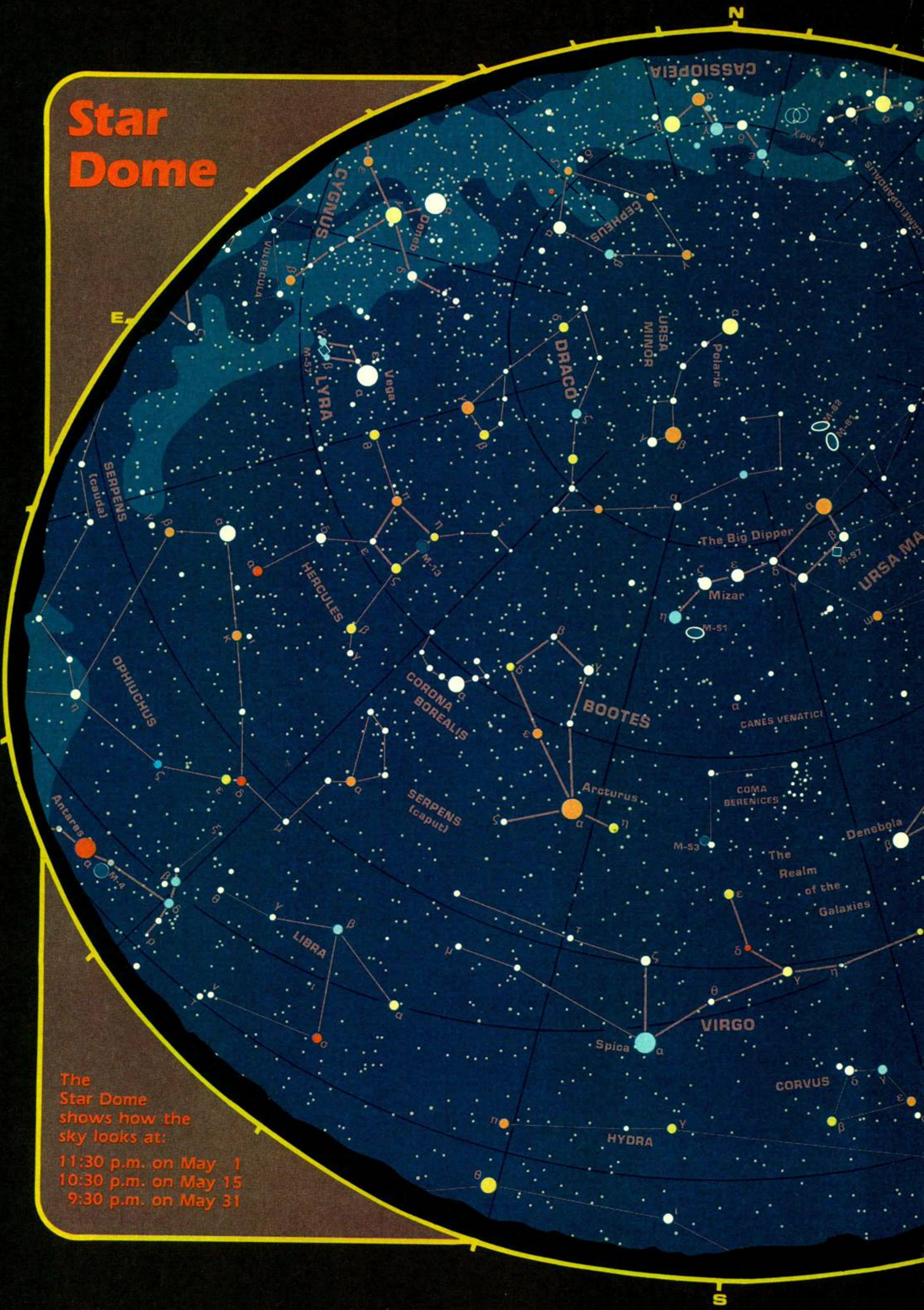
This month's penumbral eclipse occurs not far from two bright planets, which are just days past opposition — Mars and Saturn. Half the constellation of Libra separates these two retrograding worlds on May Day, but by month's end Mars has raced past Alpha (α) Librae and lies just a few degrees southwest of the star — and only a few times farther southeast of Saturn. Mars slows in June and does not quite have a true conjunction with Saturn, but it does manage a "quasi-conjunction," as we shall see next month.

Of these two prominent planets, **Mars** is by far the more impressive to the unaided eye this month. At opposition on May 11, Mars is at its brightest since 1973, a gleaming red light of magnitude −1.7. Mars is moving inward on its rather eccentric (that is, decidedly elliptical) orbit; the planet is closest to Earth on May 19, more than a week after opposition. Every other year, when we catch up to and overtake Mars, it comes to opposition for us — that is, Mars and the Sun lie 180° apart as seen from terrestrial skies. But on the past several occasions we have caught up to the Red Planet on its inbound journey to perihelion, the closest Mars gets to the Sun in its orbit. This trend continues through 1988, when Mars will be at opposition not far from the time of its perihelion. In May 1984 we approach to about 0.53 AU from Mars, but in 1986 and 1988 we will get much closer to this neighbor world, and it will loom a lot brighter.

Although this year's opposition with Mars is far from being perihelic, it is still exceptional. Mars is at its descending node (that is, it passes southward across the plane of Earth's orbit) on May 8, almost at opposition. The most interesting result of this near-perfect line-up of Sun, Earth, and Mars would be visible to a spacecraft or astronaut on Mars itself — they would see a "transit of Earth."

A transit occurs when a celestial body crosses the face of the Sun. From Earth it is possible to see a transit of Mercury about 13 or 14 times a century. (The next is on November 13, 1986.) Transits of Venus occur in pairs 8 years apart, which are themselves separated by more than a century (the last pair was in 1874 and 1882; the next will be in 2004 and 2012).

Star Dome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Mizar
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HERCULES
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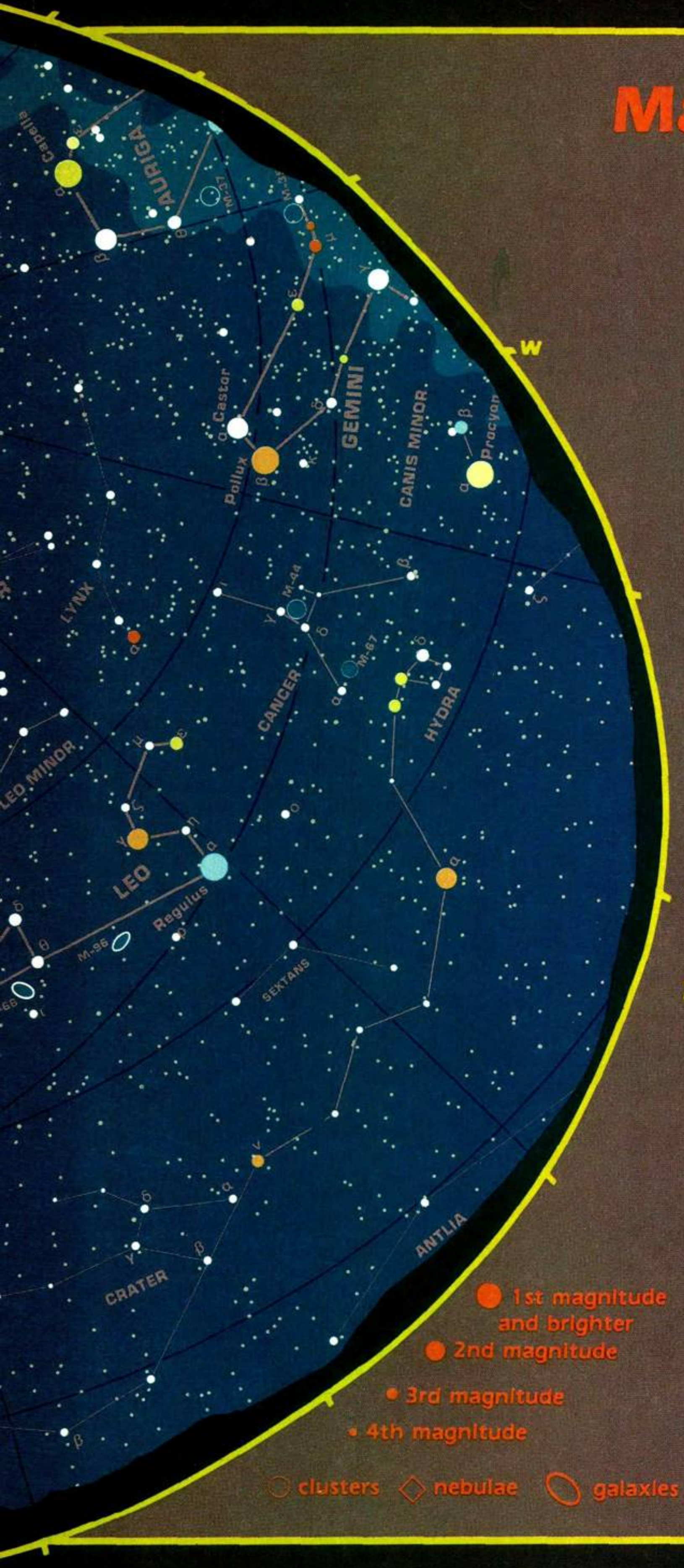
OPHIUCHUS
CORONA BOREALIS
BOOTES
CANES VENATICI
Arcturus
COMA BERENICES
SERPENS (caput)
M-53
Denebola
The Realm of the Galaxies
Antares
M-4
LIBRA
VIRGO
Spica
CORVUS
HYDRA

The
Star Dome
shows how the
sky looks at:

11:30 p.m. on May 1
10:30 p.m. on May 15
9:30 p.m. on May 31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M-96
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ANTLIA
CRATER
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

May Sky Almanac

3rd Saturn comes to opposition today.

4th The early morning hours are the best for observing the Eta Aquarid meteor shower — a stream related to Comet Halley — which reaches peak activity today.

7th Mercury passes through aphelion.

8th First Quarter Moon occurs at 7:50 a.m. EDT.

11th The Moon is at perigee at 11:08 p.m. EDT: 227,176 miles. Also, Mars is at opposition today.

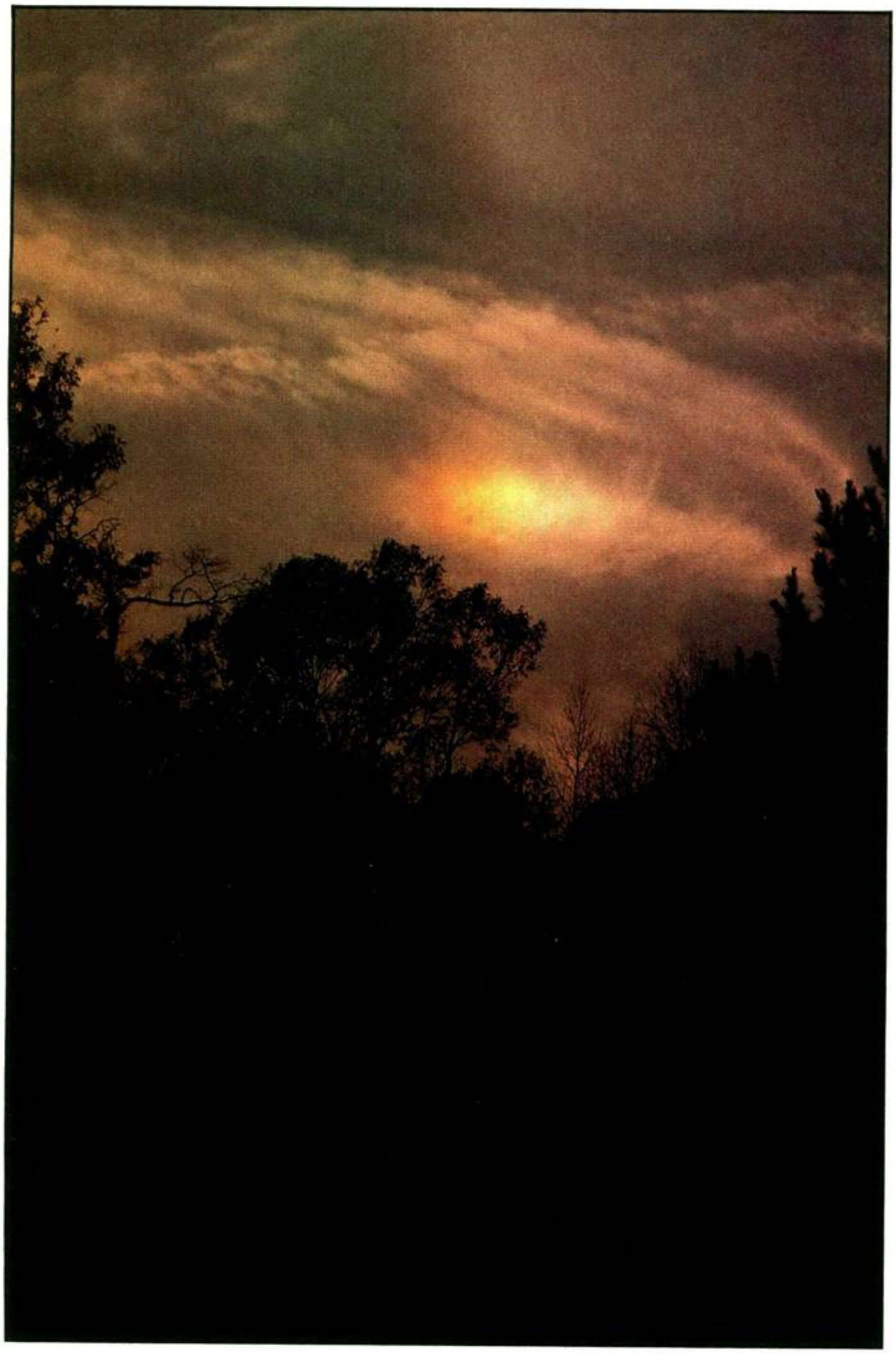
15th Full Moon happens at 12:29 a.m. EDT. At the same time, there is a penumbral eclipse, which will slightly darken the southern edge of the Moon.

19th Today, Mars is closest to Earth *for this opposition*: 49.4 million miles. Also, Mercury is at greatest elongation west in the morning sky; *unfortunately, the planet's visibility is very poor.*

22nd Last Quarter Moon occurs at 1:45 p.m. EDT.

23rd The Moon is at apogee at 9:00 p.m. EDT: 251,318 miles.

30th New Moon happens at 12:48 p.m. EDT; there is also an annular eclipse visible over almost all of North America *(see pages 34 and 50).*



When the air contains randomly oriented ice crystals, a halo can form around the Sun and Moon — at every part of the halo, some crystals must be correctly oriented to bend light to an observer. But we see only the *sides* of a halo when ice crystals align horizontally, resulting in a "sundog." Photo by L.H. Price.

In "Transit of Earth," a short story by Arthur C. Clarke, the last sight of Earth for a doomed astronaut on Mars is that of a round black disk — Earth — creeping across the Sun trailed by a much smaller dot, our Moon. The best calculations on transits of Earth from Mars, made by Brian Marsden and Jean Meeus, say that the last event occurred in 1905, and the next will not take place until 2084. If you wish to look for Mars when we are crossing the Sun from the viewpoint of that planet, go out at 9h UT on May 11.

Mars may dominate the sky during the early evening, but not far ahead of it in the nightly journey is the other planet at opposition — golden **Saturn**. When at opposition on May 3, Saturn is closest and, a few hours later, at its brightest — 0.3 magnitude. Though Saturn is getting more distant at each opposition until 1988, it increases in brightness because the tilt of its rings is increasing each year. Late in the month, watch as Mars approaches Saturn and nearby Alpha Librae.

Jupiter is only 0.3 magnitude brighter than Mars on May 11, but then continues to brighten as Mars fades. Jupiter slowly retrogrades in Sagittarius, about 4° north of the second-magnitude star Sigma (σ) Sagittarii. The real interest, however, lies in its close conjunctions with the two 5.0 magnitude stars Nu^1 (ν^1) and Nu^2 (ν^2) Sagittarii.

Jupiter does not quite retrace its path of earlier this spring, but its conjunctions with these stars are even closer than before. The planet is a bit over 2 minutes of arc north of Nu^1 at 4h UT on May 21. But at 11h UT on May 17, the center of Jupiter is less than one Jupiter-diameter south of Nu^2 — just 39 seconds of arc away! No naked-eye star has been so close to Jupiter since the planet occulted Beta (β) Scorpii in 1971; none will be closer until 1995 (at least a near occultation) and 1996 (Nu^2 again — this time, surely an occultation). Due to the bright, nearby Moon during this month's close encounters, you'll need binoculars to observe Jupiter's approach and departure from Nu^1 and Nu^2.

While Mars, Jupiter and Saturn excel in May (as do Uranus and Neptune, which we will examine next month at their oppositions), the inner planets are poorly placed. **Mercury**'s 25.6° elongation on the 19th is a morning one, hence very poor for mid-northern latitudes — you may not be able to find it low in the east in late morning twilight. Venus is even worse — though there is a small chance that someone might just glimpse it (taking due precautions) about 4° west of the Sun during the annular eclipse.

Finally, in this month of so many superb events, you should consider finding fairly dark skies for this month's **Eta Aquarid meteor shower** (see Sky Almanac). The Moon is New at its peak, providing an excellent opportunity for monitoring this important shower. The particles making up the Eta Aquarid swarm derive from Comet Halley, and studies of the shower's behavior over the next few years may teach us much.

The Starry Sky

Only three first-magnitude stars shine in the traditional spring constellations — **Regulus**, **Arcturus**, and **Spica**. High in the north, of course, is the finest second-magnitude asterism in the sky, the **Big Dipper**. And both **Leo** and **Corvus** cut quite prominent figures. Nevertheless, if you want to enjoy the spring constellations, you have to get away from the worst of the city lights. Why not reserve a temperate but clear May evening for a drive out to the universe — waiting just a few miles from your city?

You'll find the zero-magnitude orange star Arcturus even from the middle of a city, but under fairly dark skies you can trace the entire outline of its constellation, kite-shaped **Bootes** the Herdsman. The shoulders of Bootes lie between the end of the Big Dipper's handle and the small but conspicuous constellation **Corona Borealis**, the Northern Crown. Corona Borealis is adorned with second-magnitude **Alphecca**, which is also called Gemma.

The constellation in which Spica lies is dimmer and much larger than Bootes, but is better known, being a member of the zodiac. **Virgo** the Virgin is depicted as a maiden (sometimes with wings) who is reclining with an ear of wheat at one hip. Spica means "ear of wheat" and marks that position in the figure. You'd do best to learn the rest of Virgo with a star map at your side (see Star Dome).

Once you manage to organize the stars of Virgo into a pattern you can recognize, you are ready to learn more about some of them. North and well west of Spica is **Porrima**, Gamma (γ) Virginis, a fine telescopic double star. Continuing northwest up Virgo's body, we come to fainter fourth-magnitude **Eta (η) Virginis**, which lies almost on the celestial equator. Still farther northwest, **Beta (β) Virginis** marks the head of Virgo, the brightest star in the sky near the autumnal equinox (the intersection of the ecliptic with the celestial equator, and the position of the Sun on the first day of autumn). The lower extremities of Virgo are composed of still fainter stars that extend up between Arcturus and the current position of Saturn.

Some fainter constellations are also worth knowing about. Just north of Virgo's head and east of Leo's tail is the constellation **Coma Berenices**, Berenice's Hair. In this region of Coma and Virgo is the densest of all concentrations of bright galaxies. There are several clusters of galaxies in this region of the heavens, and they represent part of one of the largest structures in the known universe — the Local Supercluster. But you'll need a telescope to see even their brightest members. You do not need a telescope to see the **Coma star cluster** (Melotte 111), a lovely disheveled grouping visible on a clear spring night — but you'll need rather dark skies to appreciate this cluster fully.

Last month we examined **Canes Venatici**, whose brightest star is **Cor Caroli**. It is located north of Coma Berenices and forms with the stars Arcturus, Spica, and Denebola (the tail end of Leo) a vast figure called the "Diamond of Virgo." The stars form an excellent progression: Arcturus (−0.1), Spica (1.0), Denebola (2.1), Cor Caroli (2.9). The southern half of the diamond forms a remarkably good equilateral triangle about 30° to 35° on each side. Compare this triangle of Arcturus, Spica, and Denebola with the one formed by Arcturus, Spica, and Alkaid (the end star of the Big Dipper's handle) — the two are amazingly similar in size and shape.

Skylore

Over thousands of years the planet Mars has terrified our species as a god of war, threatened as a source of alien invasion, and beckoned as a far-off land of adventure and scientific exploration.

In ancient times, the red color and infrequent brightenings of Mars were a cause for alarm. It's easy to imagine that special fright when the alternate-year oppositions of Mars climaxed — at intervals of 15 to 17 years — with a perihelic opposition at which Mars easily exceeded the brilliance of Jupiter in a midnight sky. It's no surprise that a number of cultures regarded red Mars as the blood-stained god of war and disasters.

The Assyro-Babylonian name of the planet was Nergal, the god of battle and disease. The legends tell that Nergal, along with fourteen demons, invaded the land of the dead, forcing its ruler, Ereshkigal, to marry him. Thus he became lord of the dead. The Babylonians also knew the planet Mars as Kha-urud. The earliest rulers of Mesopotamia, the Sumerians, pictured the planets as sheep — Mars was Zal-bat-anu, the one associated with death.

Over the millennia of ancient Egypt, the Egyptians connected Mars with at least two gods, Khnum and Hor-tas. Khnum was portrayed as a man with a ram's head that had long wavy horns. He ruled the sources of the life-giving Nile. Khnum means "the Moulder," for some said he had made the world on a potter's wheel and fashioned mankind, as well. Mars was also known as Hor-tas, which is Red Horus — a war god.

The Persians knew Mars as Pahlavani Siphir, the Celestial Warrior, but also as Bahram, the Killer. A Hindu name was Skanda. In gnostic angelology the planet was Chamuel, in Hebrew medieval angelology it was Madimial. In Ceylon and Bali, Mars was Angare; in Arabia, Mirrikh. The Chinese called the planet Huo Hsing (Fire Star), and said it controlled the heart and was associated with wood fires, lightning, incense, iron, and bitter taste.

Our week is probably seven days long because the ancients knew the Sun, Moon, and five planets, and assigned one day to each. In English, Tuesday is derived from Anglo-Saxon god Tiw — for he was associated with the Roman Mars whose day this was. Modern speakers of the Romance languages (those that stem from Latin, such as French, Spanish, Italian, Portuguese, and Romanian) can more easily see that the third day of the week (after Sun-day and Moon-day) is that of Mars. Note that modern French for Tuesday is *mardi* — as in Mardi Gras (Fat Tuesday).

The entire lunar disk may be visible when the Moon is crescent. As seen from our neighbor world, a Full Earth is some 45 times brighter — around magnitude −17 — than the Full Moon that shines in terrestrial skies. The night side of the Moon in Dennis Jamison's photo glows by "earthshine."

Mars also gave its name to the month we call March. Until 153 B.C., the Roman Republic had March (actually "Martius") as the first month. The year began roughly at the time of the vernal equinox before it was moved back to near the solstice. That the Romans should honor Mars with the first month of the year is not too surprising, considering their high regard for martial affairs. The word *martial* itself is derived from Mars.

Most of us know that Mars was the name of the Roman god of war (Greek Ares). But there is so much to say about the gods Mars and Ares that they will be accorded a Skylore section of their own here in the future. Yet another installment should be devoted to the modern lore of Mars, which we owe to Percival Lowell, H.G. Wells, Edgar Rice Burroughs, Ray Bradbury, and other writers who have helped to prepare us for the real-life adventures of the Viking spacecraft.

These spacecraft have revealed still more mysteries — such as the Pyramids of Elysium, the vast, regular pyramid-shaped structures in one part of Mars. And in the lifetime of some of you reading this, we will perhaps have legends truly *of* Mars — that is, legends from people who explore or even live on the Red Planet.

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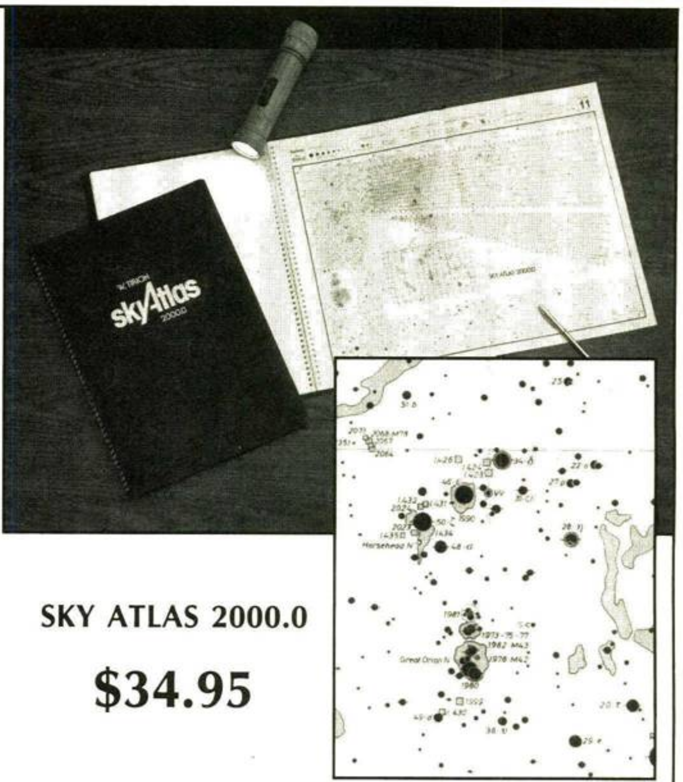

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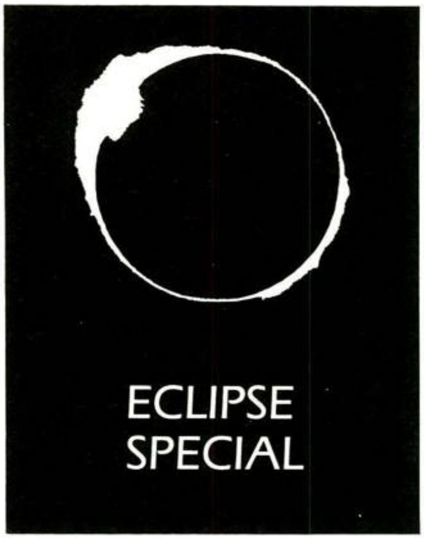


How to Observe and Photograph the Annular Solar Eclipse

by Allen Seltzer

The upcoming annular eclipse on May 30 (see Gazer's Gazette, page 34 this issue) offers you a fine opportunity for some interesting sights — and even some important observational projects. It also offers you an excellent chance to go blind.

Annular eclipses are dangerously tempting events — and this one more than most because it is so very nearly total. The Sun's light will appear to be greatly dimmed by the interposed Moon, and you'll feel a powerful temptation to follow the progress of the eclipse by looking directly at it. Suppress any such urge *ruthlessly*. At NO time should you observe the Sun, partially eclipsed or not, without using proper filters to protect your eyes.

The light from even the small areas of uncovered Sun will be extremely intense during this eclipse, and unprotected looking could result in permanent blindness. There has been a lot of speculation that since this annular eclipse will be very close to total, the solar chromosphere, prominences, and corona may be visible briefly at mid-eclipse. Don't bet your eyesight on it. The uneclipsed portion of the Sun's photosphere is thousands of times more brilliant than even the brightest parts of the corona — and enough photosphere will be showing to drown out any corona.

The simplest and safest way to observe and photograph an annular solar eclipse is by optical projection. When you throw an image of the Sun onto a white sheet or screen, you avoid observing the Sun directly and, at the same time, provide a show that many people can stand around and watch safely. The optics can be those of a monocular, a pair of binoculars, or a telescope. Place the viewing screen — which can be a sheet of stiff white cardboard or the artist's material called "Foamcore" — perpendicular to the instrument's optical axis and some distance back of the eyepiece. Shielding the screen from direct sunlight will improve the contrast of the projected image, so make a cardboard shade and mount it on the instrument near the eyepiece in such a way that it throws a shadow on the projection screen.

Solar Image Size vs. Focal Length

Focal Length (mm)	Image Size (mm)	Image Size (in)
50	0.5	0.02
100	0.9	0.04
200	1.8	0.07
300	2.8	0.11
400	3.7	0.15
500	4.6	0.18
600	5.5	0.22
1000	9.2	0.36
1200	11.0	0.43
1500	13.0	0.54
2000	18.4	0.72

Then, *without looking through it*, aim your scope at the Sun and adjust it until the Sun's image appears on the screen. You'll find the size of the projected solar image depends on both how far the screen is from the eyepiece and what magnification the instrument is delivering. The farther the screen is from the eyepiece, the bigger the image, but as it gets larger the image also gets dimmer. Switching to a shorter focal length eyepiece will yield a larger image without dimming the image as much.

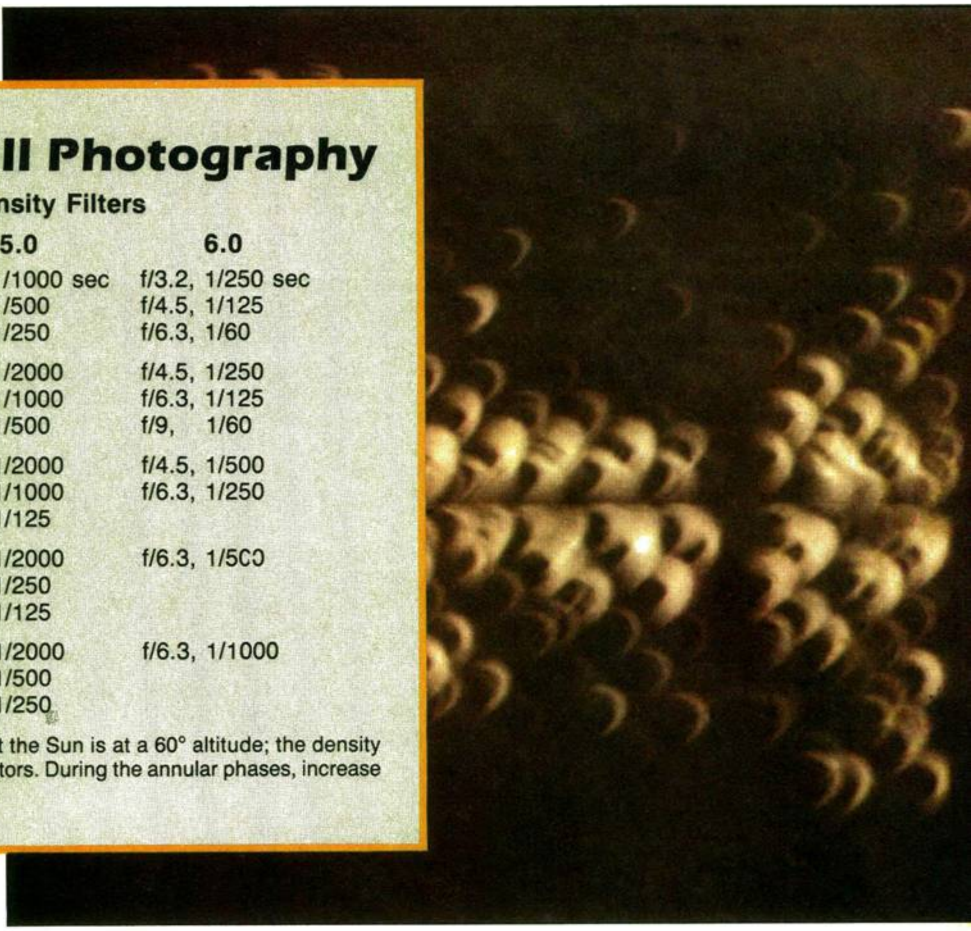
If you're using a regular astronomical telescope, cover or remove any guidescopes or finders, and make sure that someone with good sense will be attending the instrument at *all* times. Excited children — and adults — do totally brainless things on occasion, and it's up to you to see that none of your spectators come to grief.

When choosing an eyepiece, be sure that its field of view is big enough to encompass the entire Sun (about 30′ of arc). Ideally, the true field of the eyepiece should be at least 45′. Avoid using compound eyepieces that contain cemented lens elements — the objective lens or mirror will focus intense heat on the eyepiece and "cook" it. Simple Ramsden oculars are well suited for solar projection. If you plan to use a monocular or binocular, keep in mind that most of these have Kellner or other types of compound oculars with cemented optics, so they should be used for brief intervals only. In fact, it's good practice not to use *any* optical device for prolonged solar projection, as even simple lenses have been known to crack under the concentrated heat of the Sun.

You can minimize heat buildup by keeping all optical surfaces clean. Dirty lenses, especially eyepieces, absorb more heat than clean, dust-free ones. And why use your instrument's full aperture? Stop it down; 4 inches is more than ample. With larger optics the heat — and the risk to eyepieces — increases greatly.

Did you know that you can also use projection without any optical device? All you need is a well-foliated tree or, lacking such, any large flat opaque screen pierced with widely spaced pinholes. Even your own hands will do if you're really stuck. The spaces between the leaves act as pinholes and form tiny crescent or annular images of the Sun on the ground. Holding up a pierced screen to face the Sun will produce the same effect, as will criss-crossing the fingers of one hand with those of the other.

Still or movie photography of a projected solar image is relatively easy. Used this way, almost any camera, including the simple non-adjustable kind, can document the eclipse. With adjustable



Exposures for Still Photography

ISO/	Density Filters		
ASA	4.0	5.0	6.0
25-32	f/11, 1/2000 sec	f/5, 1/1000 sec	f/3.2, 1/250 sec
	f/16, 1/1000	f/8, 1/500	f/4.5, 1/125
	f/22, 1/500	f/10, 1/250	f/6.3, 1/60
50-64	f/16, 1/2000	f/5, 1/2000	f/4.5, 1/250
	f/22, 1/1000	f/8, 1/1000	f/6.3, 1/125
	f/32, 1/500	f/10, 1/500	f/9, 1/60
100-125	f/22, 1/2000	f/8, 1/2000	f/4.5, 1/500
	f/32, 1/1000	f/10, 1/1000	f/6.3, 1/250
	f/14, 1/500	f/9, 1/125	
200-250	f/32, 1/2000	f/10, 1/2000	f/6.3, 1/500
	f/14, 1/1000	f/9, 1/250	
	f/20, 1/500	f/13, 1/125	
400-500	not recommended	f/14, 1/2000	f/6.3, 1/1000
	f/20, 1/1000	f/9, 1/500	
	f/28, 1/500	f/13, 1/250	

These assume that the sky is clear and that the Sun is at a 60° altitude; the density filters are Kodak #96 neutral density attenuators. During the annular phases, increase your exposure by one stop.

cameras, determine the exposure directly from the screen using the camera's internal meter or a light meter. Depending upon how large the projected solar image is in the viewfinder and the camera's metering pattern, some adjustment in the exposure from that indicated may be necessary.

To gauge exposures better, it's sensible to make a trial run with the same equipment and film you'll use for the eclipse. Try to photograph the Sun near the altitude it will have on eclipse day for your site, and make careful notes on the exposure settings and the sky conditions. The results of the test roll(s) will help you establish the main setting you'll use throughout the partial phases. As second contact approaches, increase the exposure by about one stop to compensate for the dimming. (More on exposures later.)

When you photograph the Sun's image from a projection screen, keep the camera's film plane as nearly parallel to the screen as possible to avoid distorting the Sun's image into an oval. Because you'll probably want to hold the camera close to the screen, a macro-focusing lens of normal focal length is desirable. Anyone using a camera with a fixed-focus lens should make certain it is not too close to the screen to render a sharp image. If you're in doubt whether a given camera or setup is suitable, a trial roll or two should point out any problems.

You can also photograph the crescent and annular images produced by pinholes, but solar images produced this way will not be nearly as bright, contrasty, or as sharp as those obtained by optical projection. Nevertheless, give it a try — you'll get some interesting photographs of the various stages of the eclipse. Once again, use your light meter to determine the proper camera settings.

To enhance the scientific value of your eclipse photographs, especially those of the annular phases, attach an accurate watch with a sweep second hand to the projection screen so that the time may be recorded on film along with the eclipse. To synchronize the watch, get the time signal from the U. S. Naval Observatory by phoning (900) 410-8463 or by tuning in WWV, a radio station operated by the National Bureau of Standards at shortwave frequencies of 2.5, 5, 10, 15, and 20 MHz. If you use a video or sound-on-film motion picture camera, you could record the WWV broadcast directly on tape or film along with the eclipse by using a portable receiver set-up.

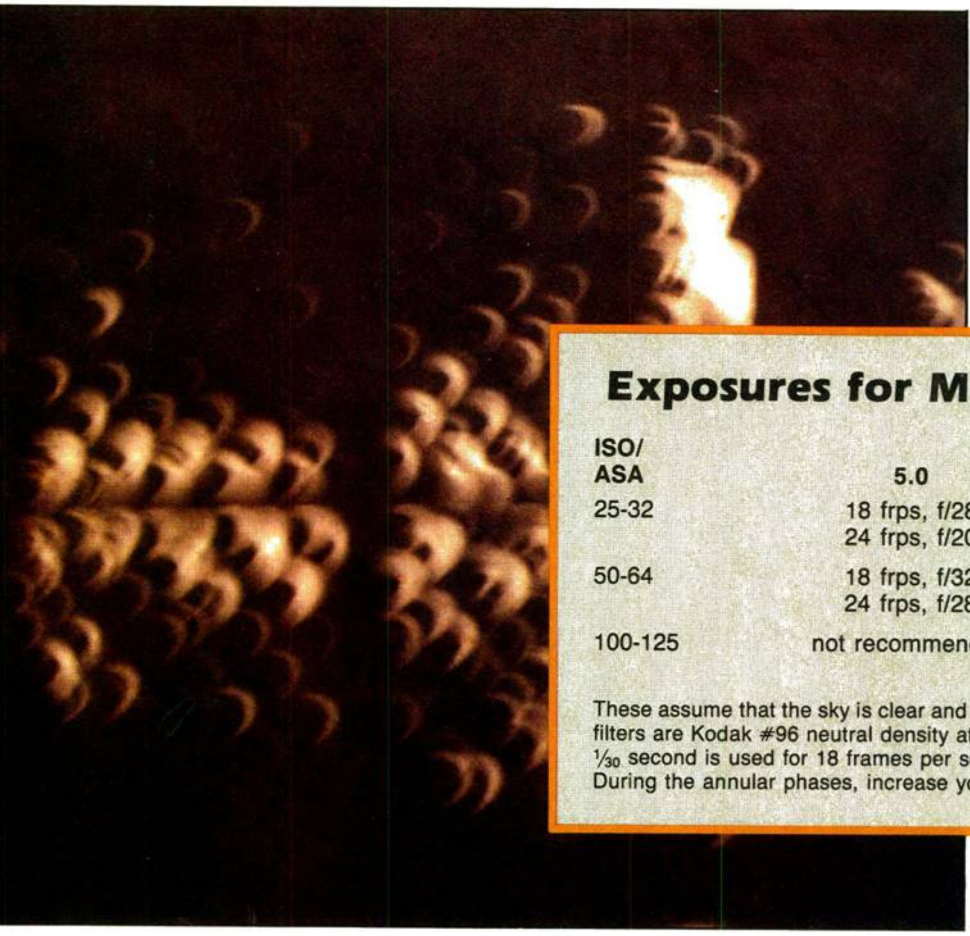
Direct optical methods are required for the highest-quality still or motion pictures of the eclipse. Because of the Sun's (and Moon's) rather small angular size, some type of telephoto or telescopic lens system is essential.

The size of the image of a particular subject on film is a function of the angular extent of that subject and the focal length of the optical system being used. The following simple formula may be used to determine the size (on film) of the solar image for May's eclipse:

$$\text{Sun image size} = 0.00918 \times \text{effective lens focal length}$$

where 0.00918 is the angular size of the Sun in radians. The image size is in whatever units you used to measure the effective focal length (see box on the opposite page). Notice that the size of the solar image produced by a 50mm lens (the so-called "normal" focal length for 35mm cameras) comes out to only 0.46mm, or $\frac{1}{55}$ inch — about the size of a pinhead! This is why you need long focal length optics for detailed eclipse photography.

Your choice of focal length will depend, in part, on the film format you have. Essentially, you want to choose a focal length that will provide an image of the Sun that comfortably fills the frame. For 16mm movie film, whose frame dimensions are 7.5mm x 10.3mm, select a lens with a focal length between 300mm and 600mm. For 35mm still cameras, whose frame size is approximately 24mm x 36mm, a 600mm to 2000mm focal length is best. Cameras with 2¼'' (6 x 6 or 6 x 7 centimeter) format can handle focal lengths up to 5000mm, making them well suited for larger telescopes with longer focal lengths. Most portable home video cameras as well as 8mm and Super 8 movie cameras have non-interchangeable zoom lenses. With these, set the lens at the maximum focal length.



Tiny cracks in the thatched roof of a house in India acted as a pinhole camera during a solar eclipse, casting a multitude of crescent Sun images on the floor. Photo by Allen Seltzer.

Exposures for Movie Photography

ISO/ ASA	Density Filters 5.0	6.0
25-32	18 frps, f/28 24 frps, f/20	18 frps, f/9 24 frps, f/6.3
50-64	18 frps, f/32 24 frps, f/28	18 frps, f/13 24 frps, f/9
100-125	not recommended	18 frps, f/18 24 frps, f/13

These assume that the sky is clear and that the Sun is at a 60° altitude; the density filters are Kodak #96 neutral density attenuators. The equivalent shutter speed of 1/30 second is used for 18 frames per second (frps) and 1/60 second for 24 frames. During the annular phases, increase your exposure by one stop.

In order to photograph the eclipse directly, the brilliance of the Sun must be greatly attenuated — as much as ten thousand to a million times — before it hits the film. The best way to do this is with a metal-coated glass or Mylar Sun filter that fits over the objective lens or mirror. This keeps the intense solar heat out of the optical system altogether. Several telescope and optical manufacturers offer such filters, which are safe for both visual and photographic observation of the Sun. (One plus is that you can then use the full aperture of your scope and get the best possible resolution.)

However, you should be aware that these filters will alter the color of the Sun's image in a way that depends on the metal used for the coating. Usually, the color isn't too objectionable. Chromium coatings render the solar image orange and aluminum ones add a blue cast. Recently, filters have been manufactured using Inconel, the tradename for a nickel-base alloy containing 16% chromium and 7% iron. In addition to its high corrosion and oxidation resistance, Inconel provides a very pleasing yellow-white image of the Sun.

You'll have to take a trial roll or two to establish the exposure data for your Sun filter because of the wide differences in transmission properties. (Sometimes the company that manufactures or markets the filter will supply guidelines.) The exposure obtained for the Sun's full disk may be used throughout most of the partial phases. A minute or two before second contact, increase the exposure by one full stop.

By the way, this sounds obvious, but it's very important to make sure that the Sun filter is securely mounted on the instrument. You'd hate to have a sudden gust of wind blow it off while you were looking through the scope! (And remember to keep the filter on during the annular phases.)

Another way to reduce the brightness of the Sun's image is with neutral density filters — more appropriately, neutral density attenuators. These are nice for color photographs since they impart no color of their own to the image. But beware: neutral density attenuators are almost completely transparent to parts of the infrared spectrum and must therefore never be used for visual observations of the Sun. It appears deceptively safe to view the Sun through attenuators of sufficient density, but the infrared radiation they pass can damage your eye — and you won't know what's happened until it's too late.

As with metal-coated filters, place the neutral density attenuators in front of the objective lens or mirror. You can focus and aim the instrument by using two sheets of aluminized Mylar or other visual solar filter in place of the neutral density attenuator. After you've got the image centered and focused, swap the visual filter for the attenuator.

Eastman Kodak markets neutral density attenuators, referred to as Wratten #96 filters, made of gelatin in sizes up to 75mm (3 inches) square. Larger sizes may be obtained by special order. These filters also come in a range of densities from 0.1 to 4.0. The values used to designate densities of Wratten #96 filters are logarithmic. Thus a filter with a density rating of 1.0 will transmit 0.1 or 10% of the incoming light, a 2.0 density filter will pass 0.01 or 1%, and so on. Depending upon the effective focal ratio (f/number) of your optical system, the speed of the film, and the desired exposure time, Wratten #96 filters with densities of between 4.0 and 6.0 are most desirable. Bear in mind that you can build up the necessary density by combining two filters. You'll find exposure data for attenuators of several different densities in the tables above and on page 51.

If you want to view the eclipse directly *without* optical aid, several low-cost filters are available. Of course, the metal-coated glass and Mylar Sun filters mentioned earlier work fine, but you can also make a good visual Sun filter from most black and white photographic films. After being developed, these films contain silver particles, which are opaque to infrared radiation. Thus they are safe (given adequate densities) for brief periods of solar viewing — less than 15 seconds at a time. But never use color films as Sun filters; the protective particles of silver are bleached out of color films during

Photo and Movie Films

Film		ISO/ ASA	Type	Availability	Recommended Uses
Kodachrome	25	25	CT	35mm	B, C
	64	64	CT	35mm	A, B, C
Ektachrome	64	64	CT	110, 126, 127, 35mm	A, B, C
	200	200	CT	126, 35mm	A, B, C
	400	400	CT	120, 35mm	A, C, D
Fujichrome	R-100	100	CT	35mm	A, B, C
	R-400	400	CT	35mm	A, C, D
Agfachrome	64	64	CT	35mm	A, B, C
Kodacolor	VR-100	100	CN	35mm	A, B
	II	100	CN	110, 126, 116, 616, 120, 620, 127, 828, 35mm	A, B
	VR-200	200	CN	35mm	A, B
	VR-400	400	CN	35mm	D
	VR-1000	1000	CN	35mm	D
Fujicolor	F-11	100	CN	110, 126, 120, 35mm	A, B
	F-11 400	400	CN	110, 35mm	D
Panatomic-X		32	B&W	120, 35mm	A, B
Plus-X		125	B&W	120, 220, 35mm	A, B
Tri-X		400	B&W	126, 120, 35mm	A, D
Royal-X		1250	B&W	120	D
Kodak 2475		1250	B&W	35mm	D
Ilford HP-5		400	B&W	35mm	D
Eastman Plus-X Reversal 7276		50	B&W movie	Super 8, 16mm	A, B
Eastman Plus-X Reversal 7278		200	B&W movie	Super 8, 16mm	A, B
Eastman Plus-X Negative 7231		80	B&W movie	16mm	A, B
Eastman Plus-X Negative 7222		250	B&W movie	16mm	A, B
Kodachrome II		25[1]	CT movie	8mm, Super 8	A, B
Ektachrome 160		100[1]	CT movie	Super 8	A, B
Ektachrome MS		64	CT movie	16mm	A, B
Eastman Color Negative 7254		64[2]	CN movie	16mm	A, B

Speeds:

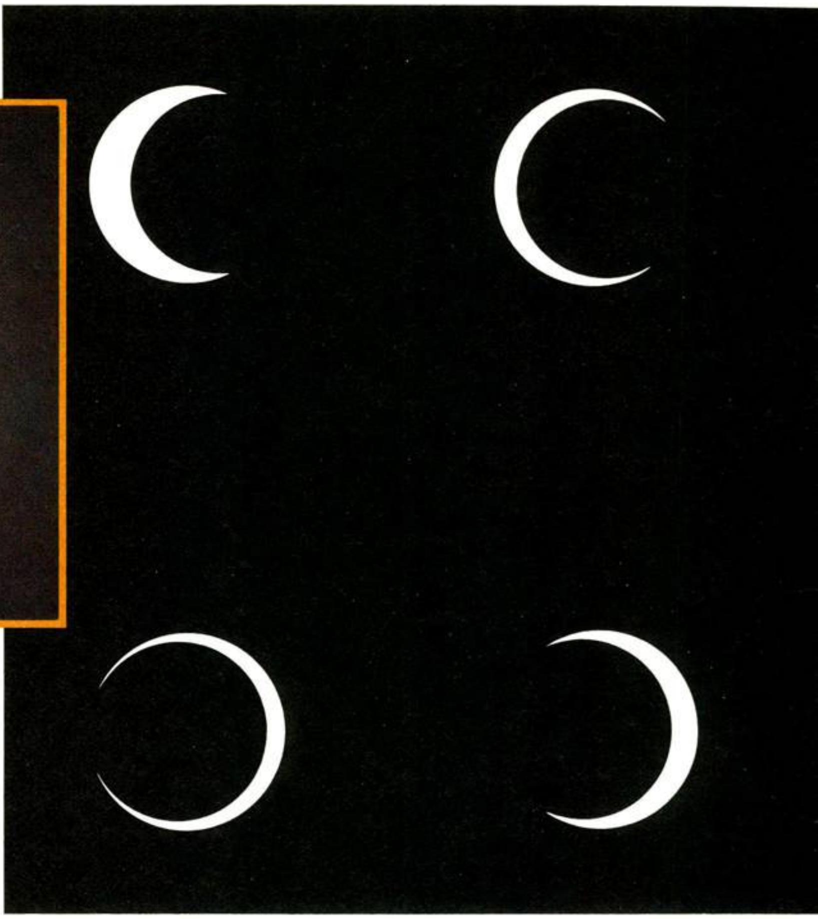
1) This is daylight speed; you'll need a type A filter as well.
2) This is daylight speed; you'll need a #85 filter as well.

Types:

CT = color transparency, CN = color negative

Recommended uses:

A — photographing projected solar image
B — photographing Sun with neutral density attenuator or metal-coated Sun filter
C — photographing sky and landscape
D — photographing shadow bands



Above: Two layers of Mylar solar filter will protect your eyesight and let you observe the eclipse safely. Right: Taken in December 1973, this series shows the stages during a true annular eclipse. Photos by Allen Seltzer. Far right: Optical projection is a safe way for many people to observe and photograph the eclipse at one time. Photo by Roger Coryell.

processing, and they are almost completely transparent to the infrared.

Go for black and white films like Kodak's Panatomic-X, Plus-X, or Tri-X, and get the large format size, such as a 120 roll or a box of 4" x 5" sheet film. Remove the film from the roll or box and expose it to strong light for about a minute, then have it developed to maximum density. The processed film will appear uniformly gray. *Two* of these sheets sandwiched together will provide sufficient density for solar observing. For convenience, mount the film in a cardboard frame or between two sheets of clear plate glass. Don't use the film filter for solar photography — light scattering in the silver particles will result in a loss of image resolution.

There is another material safe for direct observation of the Sun — a #14 welder's glass. These come in rectangular glass sheets measuring approximately 50mm x 108mm (2" x 4¼") which, again, may be mounted in cardboard frames for convenience. Viewed through a welder's glass, the solar disk appears green. (They are too poor optically for photography, however.) Please note that welder's glasses of lower densities (as indicated by lower shade numbers) are *not safe* for solar viewing. Also *not safe* are sunglasses, including the mirror style, and smoked glass.

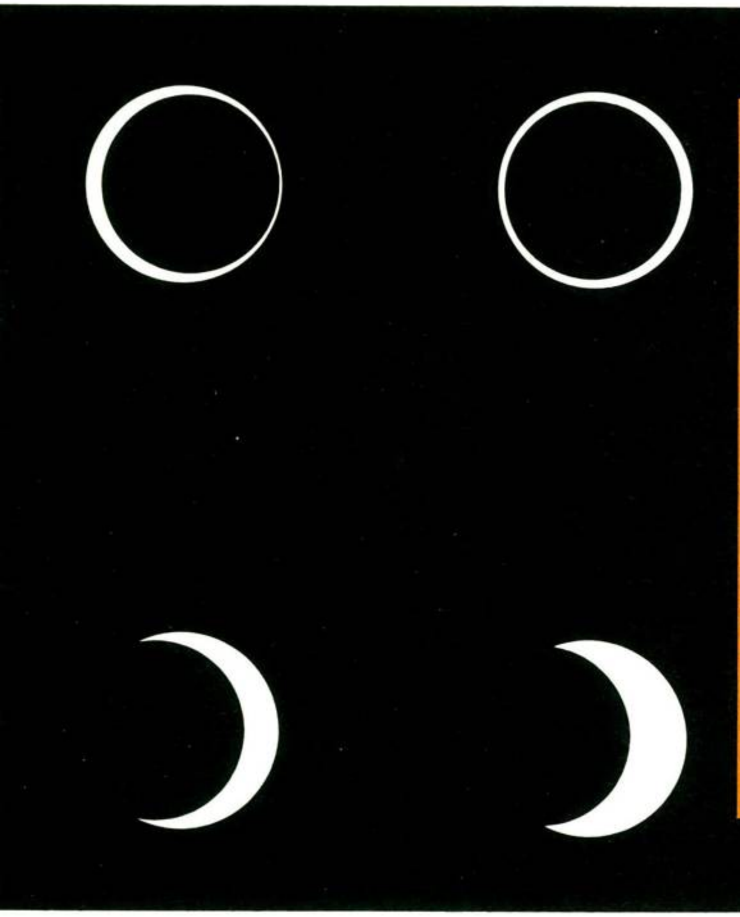
In addition to observing and photographing the eclipse itself, there will be other interesting phenomena to watch for. One is the changing sky coloration and brightness. Although the sky will not darken enough for stars to be seen, Venus will be about 4° to the west of the Sun and should be visible for those on or near the annular eclipse path. The sky will take on an eerie metallic quality as the eclipse approaches the annular phase.

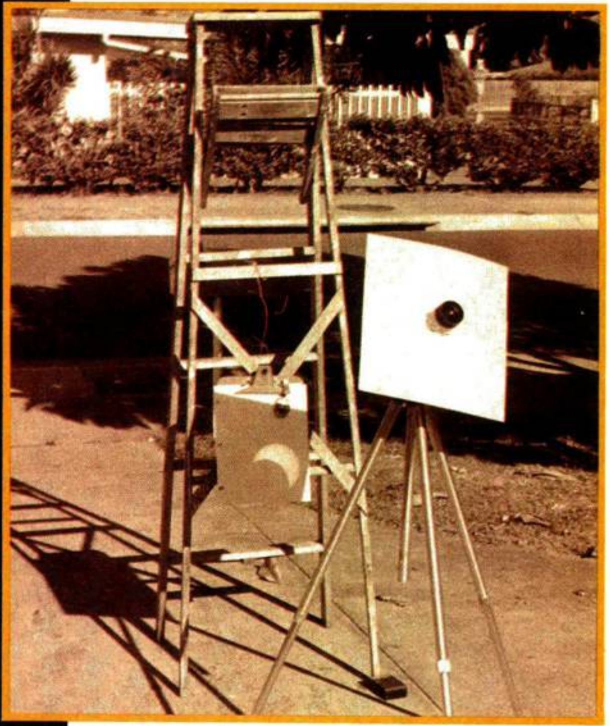
The changing color and brightness of the sky and landscape can make an interesting sequence of color slides. A normal or wide-angle lens is best for this. Determine the exposure at first contact and stick to it throughout the eclipse, snapping off a frame every 10 minutes. A dramatic movie could also be made of the varying brightness and coloration of the landscape if you shot it in stop-motion (single frame). If you're situated on the annular path, the entire eclipse from first contact to fourth will take about three hours. A single frame clicked off every 10 seconds will compress the event into 45 seconds at 24 frames per second and 1 minute at 18 frames per second. Keep to a single exposure value throughout the eclipse. (This may be just the opportunity you've been waiting for to build or rent that intervalometer!)

Another phenomenon found in total and near-total solar eclipses is shadow bands. These appear as alternate light and dark bands of varying thickness passing rapidly across the ground. They are due to irregularities in the Earth's atmosphere augmented by the ever-thinning crescent or annulus of sunlight from the eclipse. Shadow bands are not visible at every eclipse. I've seen six total eclipses and one annular and have never observed them. When shadow bands are seen, though, they usually appear just minutes before or after totality. If shadow bands are present during the May eclipse, they might very well be visible throughout the short annular phase.

It will be interesting to see whether the moving bands change direction during or after the annular part of the eclipse. If you're watching for them, pay particular attention to this. Because of the diminished light during or near annular eclipse, and because shadow bands are generally low-contrast phenomena, a large white bedsheet spread out smoothly on the ground will greatly improve your chances of observing them. And photography? You'll need all the luck you can get — shadow bands are extremely difficult to photograph and good photos of them are rare.

Make sure you have high-speed film and a fast lens; plan on short exposures. Mount the camera on a sturdy tripod and focus it on the white sheet. Place something — a notebook, say — at the center of the sheet to focus on and then remove it. Films such as Kodak Tri-X Pan (ISO/ASA 400), Royal-X Pan (E.I. 1000 to 3000, depending upon how processed), and Ilford HPS (ISO/ASA 400) are excellent. When you've taken the shots, plan on pushing the contrast brutally in processing. Consult the *Kodak Darkroom Data-Guide* or the *Photo Lab Index* for the





necessary data if you're doing it yourself — otherwise instruct your photofinisher.

Select the fastest shutter speed your camera has, and choose the appropriate f/stop with your meter. If you meter directly off the white sheet, open the lens another two stops from what it says. This is necessary because light meters assume an average 18% reflectance — considerably darker than a white sheet. Lay a meter- or yard-stick on the sheet for gauging the thickness and spacing of the shadow bands.

For the "main events" of the eclipse, several fine films are available. For direct solar photography, you don't need fast films. In fact, slower films that have finer granularity and overall better definition are desirable. In general, negative films (intended for prints) have greater exposure latitude than the transparency films. If you're in doubt about what exposure to use, choose a negative film. Black and white negative films provide additional exposure latitude and are generally sharper than their color counterparts. Furthermore, there is much greater processing flexibility with black and white films. The choice of film will largely depend upon which aspect of the eclipse interests you the most and what kind of final product — slides, prints, movies, etc. — you want. The table on page 53 summarizes still and movie films recommended for various aspects of solar eclipse photography. Additional information about each film may be obtained from the manufacturer and from such standard reference books as the *Photo Lab Index*.

One part of making your eclipse record scientific is knowing *where* you are and *when*. Many observers tape-record their field log; if you record a WWV receiver and the sound of the camera's shutter together, you'll have a good reference standard. Timings must be made to within a fifth of a second or better. As the annular phase will be very short, a motor drive or auto winder for a still camera will be very useful. A frame taken every half second or so will nicely document whatever changes occur in the annulus. Of course, a movie or video camera will be a great help, as it can record up to 30 images or more a second.

The U.S. Naval Observatory is interested in obtaining eclipse observations to determine whether the size of the Sun's photosphere is changing. The data would be most useful from observers at or close to the predicted limits of the annular eclipse path, and any technique — projection or direct, visual or photographic — can be of use. Try to identify your observation site on a topographic map to within one foot of any reference points. If you view the eclipse from a city or town, then note your exact location on a street map. The address and distance of a nearby house or building would also be helpful.

At or near the limits of the annular path, it will be important to note whether the eclipse was completely annular and, if so, the duration of the annulus, again to within a fifth of a second. (Use a stopwatch.) For those observing well inside the limits, the duration of the annular phase will be important, as will the precise times of second and third contact. Also of interest are reports of Baily's beads and any breaking up of the annulus into "diamond rings." Include in your report information on sky conditions, unusual occurrences, estimates on the reliability of the timings, and equipment and procedures you used.

An eclipse report coupon is provided in the United States Naval Observatory *Circular No. 166* by Alan D. Fiala and Marie R. Lukac. If you're going to submit photographs, movies, or video tapes with your report, don't send originals but high quality copies that can be kept on file at the Observatory. The Circular also contains charts showing the entire annular eclipse track (on land), lunar limb profiles, predicted times of contacts for hundreds of locations in the United States, Canada, Mexico, and elsewhere, elements of the eclipse, and helpful weather information for selecting an observing site. Get a copy of the Circular by writing to the U.S. Naval Observatory, Washington, DC 20390.

Allen Seltzer is a staff member at the Hayden Planetarium of the American Museum of Natural History in New York City.

ASTRONOMY
Reviews

The Left Hand of Creation
John Barrow and Joseph Silk
219 pages, hardcover, $17.95
Basic Books (1983)

At the precise instant of creation, as well as beyond that singularity, extends a region so utterly obscure that the majority of scientific investigators refuse to speculate about it, contending that such non-testable speculation is outside the proper realm of science and is best left to philosophers and theologians. The oldest riddle is, of course, the enigma of creation.

It *is* possible, however, to theorize and extrapolate backward to the very threshold of creation. This is the apparent aim of *The Left Hand of Creation*, the product of astronomers Joseph Silk and John Barrow. Silk is the author of the eminently readable *The Big Bang*, published a couple of years ago.

This work is non-technical in the sense that little mathematics is used. Nonetheless, the authors assume that their reader possesses an elementary understanding of major structures of the universe such as galaxies, interstellar matter, stellar formation and evolution, and black holes.

Clarity, unfortunately, is not a salient feature of the book. While the subject matter is not excessively complex at the level at which it is presented, some readers might find themselves re-reading sentences, paragraphs, and entire sections in an attempt to digest ideas partially obscured by unclear writing. Still, armed with a fundamental grasp of the basic principles of cosmology and a willingness to plod through some occasional murky prose, the reader will find a wealth of current cosmological thought in this volume, as well as some intriguing ideas on the inception of the universe.

By looking far back, it is possible to detect the most distant and primitive stars, or at least their remnants. Appropriate measurements and calculations can then be made, which result in an approximate age for the universe. Assuming there actually *was* a specific beginning point — and some scientists even dispute this — statements can be made that describe the state of the universe during several exceedingly brief periods of time ("eras") immediately following the instant of creation. Such eras are populated by minute particles that display highly unusual characteristics. The nearer the singularity, the more bizarre the particles and their behavior; finally a point is reached — the singularity of creation itself — where conditions are alien to our presently accepted physical laws.

A significant part of this book deals with the fascinating aspects of particle physics and the strange phenomena these tiny bits of matter manifest. The authors introduce an array of real and theorized particles such as quarks, gluons, photinos, gluinos, pions, sleptons, Zinos, and Winos. A glimpse into the world of the quantum reveals equally interesting concepts such as negative energy, antimatter, cyclic universes, evaporating and exploding black holes.

Much of the material in the book is unabashedly speculative. Do we, for instance, live in Kurt Goedel's non-expanding, rotating universe, in which time travel is a possibility? Or perhaps in Edward Kasner's pancake universe, which constantly flattens as it expands? On the other hand, we may be residing in Charles Misner's "Mixmaster" universe, in which the finite universe writhes in a series of oscillations, altering its shape continually. Though the authors do not imply such constructs are correct, they present them as food for thought.

Time is not an absolute, flowing at a constant rate. Its passage is governed by the local environment of the clock that measures it. The variables are the speed at which the clock may be traveling and the gravitational field acting upon it — these are Einsteinian axioms. But Barrow and Silk open the door to questioning this. Maybe time can be measured exactly only through a direct connection to the density of matter existing in curved spacetime.

Could it be, the authors ask, that somewhere in the relatively near future we will find that the usual redshifts of long-observed, remote galaxies are swinging toward the blue end of the spectrum? Such a signal would imply an eventual "Big Crunch" and would support the closed universe theory.

In their concluding chapter, the writers state, "Any reader who has read this far will have begun to realize that cosmology is not only about stars, galaxies, and the unending vistas of space." Indeed, with its emphasis on elementary particles, the book is definitely not a direct study of observable astronomical objects.

Several provocative questions are posed in this final chapter. Is there an ultimate elementary particle? Since no firm evidence exists, the authors surmise that there simply may be no discrete particles; perhaps infinite divisibility is a universal law. Can we imagine a total absence of matter, space, motion, and time? If so, we may also be able to throw open a window on the singularity, one allowing us to peer through to the other side. Is it possible that the universe exists under the direction of a sort of Grand Designer, a supreme intellect responsible for the wherewithal for our ultimate existence? Heavy thoughts.

According to Barrow and Silk, "Things are now as they are because they were as they were." Trite, perhaps, but one way to begin to know how things were, or may have been, is to read this book. You'll do best to approach it as a lengthy "think-piece" — but the time you spend on it will be worthwhile. *Gail O. Clark.*

Second Catalog of X-Ray Sources
P.R. Amnuel, O.H. Guseinov, and
Yu. Rakaminov
103 pages, paperback, $20
Reidel (1982)

This compilation lists 677 X-ray sources known as of September 1979, practically complete to X-ray intensities of nearly 4

μJy in the 2 to 6 keV range. The catalog does *not* include the results of HEAO-2 investigations, but lists data collected by balloons, rockets, and satellites (Uhuru, OSO-7, Ariel-5, and HEAO-1) from 1964 to 1979. The authors also list possible optical and radio counterparts for the sources.

The catalog was originally published in the journal *Astrophysics and Space Science*, volume 82, pages 3-103, 1982.

Superstars: How Stellar Explosions Shape the Destiny of Our Universe

David H. Clark
202 pages, hardcover, $14.95
McGraw-Hill (1984)

An exploding star, or supernova, is one of the most violent stellar events in the cosmos. In this final paroxysm, a star ejects most of its material into space, and may give birth to a neutron star or black hole. The author, head of the space astrophysics group of Britain's Rutherford Appleton Laboratory, examines the causes and effects of these "superstars." Clark discusses ancient records of supernova explosions — as in *The Historical Supernovae*, which he co-authored — and reviews the importance of these explosions in the creation of our solar system and the biological and climatic evolution of Earth. The book contains 37 line drawings and 18 appendices that elaborate on specific topics in the text.

Principles of Stellar Evolution and Nucleosynthesis

Donald D. Clayton
612 pages, hardcover, $32;
paperback, $15
University of Chicago Press (1983)

After its original publication in 1968, *Principles of Stellar Evolution and Nucleosynthesis* quickly became a standard graduate-level textbook for students in astronomy and astrophysics. Rather than expand or update the book — and make the cost inaccessible to students — Clayton opted for a reprint edition. His new preface includes commentary and selected references to the recent literature and reviews the most important research carried out since the book's publication. This book systematically lays out the basic physical principles that apply to the origin and evolution of stars and the processes taking place within them.

Surveys of the Southern Galaxy

W.B. Burton and F.P. Israel, eds.
309 pages (plus six pull-out maps), hardcover, $46
Reidel (1983)

The present era of galactic research began about 60 years ago, when astronomers started searching the night sky for clues to the Milky Way's physical structure. One of the fundamental and persistent problems in this research has been the general scarcity of observations of the southern sky. During the past few years, however, astronomers have made substantial gains in securing fundamental data on the southern part of the Galaxy, and interpretations based on combined northern *and* southern surveys hint at balanced descriptions of galactic morphology. For professionals only, this book contains the proceedings of a workshop held at Leiden Observatory in August 1982.

Physics of Meteoric Phenomena

V.A. Bronshten
356 pages, hardcover, $74
Reidel (1983)

Meteoroids range from 10^{-12} to 10^{12} grams in mass. When these bodies enter our atmosphere, they interact with air molecules to produce a fast-moving streak of light — a "shooting star" or meteor. Along the meteor's path, air becomes ionized and reflects radio waves. The meteoroid's atoms evaporate from its surface as it heats up, and their radiation provides valuable information about the body's chemical composition. This book, the first monograph on the subject published since 1958, contains all recent results in the field of meteor physics. For a professional audience only, the book will interest researchers in meteor astronomy, meteorites, space science, gas dynamics, and plasma physics.

Understanding the Universe

Richard M. West, ed.
249 pages, hardcover, $34.50
Reidel (1983)

Subtitled "The Impact of Space Astronomy," this work gathers six technical papers on broad topics of interest to professional astronomers (ranging from solar studies to cosmology) and discusses how lifting detectors above the atmosphere has contributed to a renewed understanding of the universe and a rejuvenation of ground-based research methods.

Advances in Photoelectric Photometry, Vol. 1

Robert C. Wolpert and
Russell M. Genet, eds.
237 pages, softcover, $23.95
Fairborn Observatory (1983)

A privately published manual, *Advances in Photoelectric Photometry* is a compendium of 16 short papers, many of which are observatory reports, dealing with amateur photoelectric photometry.

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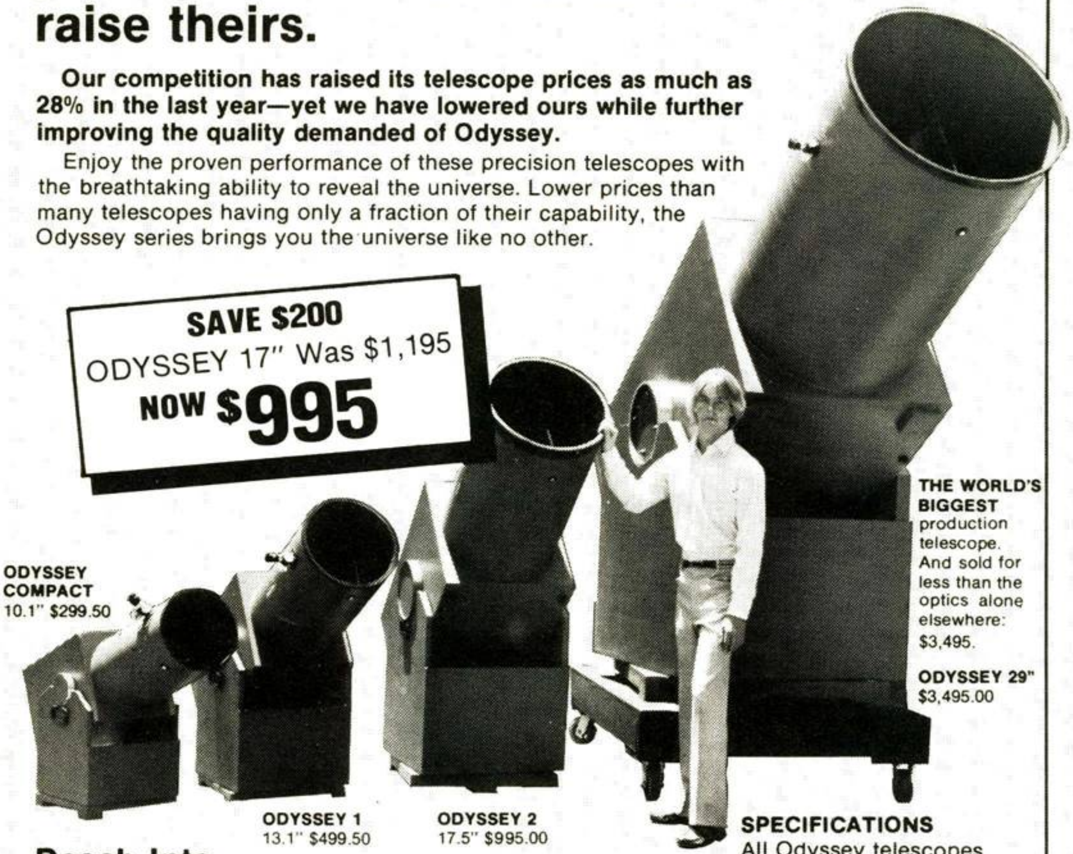

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ASTRO NEWS

Creationism and Astronomy

After the trial in Arkansas in 1981 and 1982 that pitted scientists against fundamentalist Christians, a decrease in media coverage led to the widespread belief that creationism had lost its vigor. They may not be in the news much these days, but creationists still have a strong influence on the presentation of science in secondary schools, including astronomy.

"After the Arkansas trial, creationists sort of went underground," says Robert Robbins, an astronomer at the University of Texas at Austin. "They went to work on local school boards and textbook selection committees." As a result, the coverage of any form of evolution, including the origin of the universe and the formation of stars, has altered dramatically in high school texts.

In Texas, the state selects the books used in secondary schools. Once the books are chosen, Texas makes one large order for all its schools. Thus the Texas school system is a very important market, and many textbook publishers tailor the content of their books to meet Texan standards. "A publisher isn't going to come out with another edition for the rest of the country," Robbins notes, "so kids in Montana read books that treat science in a manner that conforms to the standards of textbook committees in Texas." And, according to proclamation number 60 of the Texas State Board of Education, which governs their selection, "Textbooks that treat the theory of evolution shall identify it as only one of several explanations of the origins of humankind and avoid limiting young people in their search for meanings of their human existence." Furthermore, books that "treat the subject of evolution substantively in explaining the historical origins of man shall be edited if necessary to clarify that the treatment is theoretical rather than factually verifiable."

Obviously, biology coverage suffers the most. Gerald Skook of Texas Tech University analyzed several high school texts, including Holt, Reinhart, and Winston's *Modern Biology*, the largest selling biology textbook in the country. Skook identified 44 different topics concerned with evolution and counted the total number of words devoted to those topics. For *Modern Biology*, the maximum was about 18,000 words in 1973 — it had dropped to 13,000 words by 1981. "The most dramatic changes occur in texts put out by smaller publishers," Robbins says. According to Skook's count, the space devoted to evolution in *Biology*, published by Silver Burdett, declined by a factor of 5 — from 20,000 words in 1974 to 4,000 in 1981.

How does this affect astronomy? According to Robbins, creationists argue that star formation and stellar evolution do not take place and that the Big Bang contradicts the first and second laws of thermodynamics. They also claim that the age of the Earth is only 6,000 years and that the universe has a radius of five light-years — it only looks larger because space-time is severely curved. "Creationists have been very successful at projecting themselves as serious, learned scholars and projecting scientists as narrow-minded obstructionists," Robbins says.

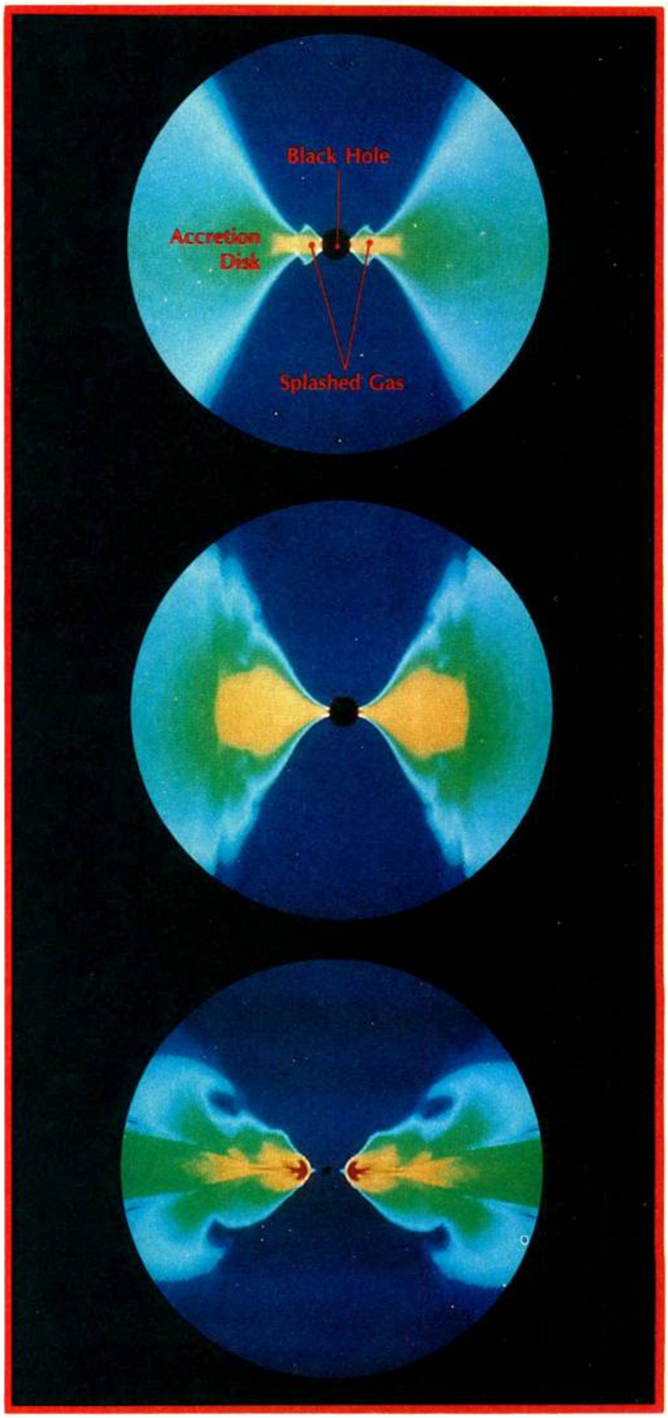
Robbins, who presented his paper at the January meeting of the American Astronomical Society, adds that creationism is particulary vulnerable when it deals with astronomy. "This is the topic where well-established scientific knowledge and the predictions of creationists differ the most," he says. "It puts astronomers in a powerful position with respect to this persistent pseudoscience."

Bacteria in Space: The Great Debate

For years, Sir Fred Hoyle and Chandra Wickramasinghe of University College Cardiff (United Kingdom) have advocated the idea that interstellar space is teeming with life.

A possible scenario for intelligent life in space, not attached to any particular planet, was first described some 25 years ago by Hoyle in a science fiction novel, *The Black Cloud*. More recently, Hoyle and Wickramasinghe have argued in books such as *Life Cloud, Diseases from Space*, and many other publications that life on Earth originated in space and that its subsequent development was (and still is) influenced by an influx of biological organisms from the cosmos.

The foundation of their theory concerns the nature of interstellar grains, the sub-micrometer-sized particles that dim the light of distant stars in our Milky Way Galaxy. Hoyle and Wickramasinghe claim that they are biological organisms, not inert minerals and ices as is generally believed. Other scientists have remained skeptical of these proposals. In view of public interest and the potentially far-reaching



A computer reveals several new features in the behavior of matter near a black hole. Each picture shows a cross-section of a disk of accreted gas. Low-density gas is colored light blue, while green, yellow, and red represent higher densities. Top and center: Hot gas nearing the black hole speeds up and becomes drawn into its equatorial plane. As the velocity of the gas increases, the material reaches a point where its centrifugal force counteracts the hole's gravity and it stops falling inward. Material behind the stopped gas splashes into it, becomes heated, and flows outward into the disk. Bottom: In another simulation, the splashed gas moves out along the *surfaces of a cool disk* (green wedge). Created by John Hawley of the University of Illinois, the simulations reveal processes that may explain variability in quasars and active galaxies, which many believe to be powered by black holes.

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implications of the theory if proved correct, a discussion meeting entitled "Are Interstellar Grains Bacteria?" took place in London, England, on November 11, 1983. This meeting, organized by the Royal Astronomical Society, was something of a landmark as it was the first time that the Hoyle-Wickramasinghe theory has been openly discussed by the scientific community, with both the proponents and their detractors, both astronomers and biologists, present in the same lecture room.

The meeting began with a paper by Wickramasinghe putting forth the case for an identification of interstellar grains with bacteria. First, he noted a remarkable coincidence in size distribution between bacteria and the particles required to explain the extinction of starlight. He also discussed absorption bands at ultraviolet and infrared wavelengths, and noted an excellent correspondence between the profile of an absorption at an infrared wavelength of 3.4 micrometers (μm; 1 μm = 10,000 Angstroms) in an astronomical spectrum and in laboratory data for the bacterium *E. coli*.

The survival of bacteria in extreme environments was discussed by D.J. Kushner of the University of Ottawa. He noted that although biological evolution is highly unlikely under the extremes of low temperatures and low pressures prevailing in space, survival of *pre-existing* organisms in those conditions is less problematical. However, J.M. Greenberg of Leiden University later described experiments in which bacteria exposed to simulated interstellar conditions in the laboratory were rapidly destroyed by ultraviolet radiation.

Comets appear to provide the most promising environment for survival. Hoyle and Wickramasinghe have argued that comets entering the solar system seeded the Earth with life, and Hoyle discussed their nature and significance in his presentation to the meeting. Cometary material in the form of meteoritic debris still rains down on the Earth, and Professor Pflug of the University of Giessen drew attention to structures found in meteorite samples that show some resemblance to fossil bacteria. Pflug also discussed one of the principal objections to the evolutionary view of the origin of life on Earth — namely, that fossil bacteria have been identified in terrestrial rocks approximately four billion years old. This is uncomfortably close to the age of the Earth, and leaves little time for organisms to have evolved from the "primordial soup."

The first speaker to question the Hoyle-Wickramasinghe hypothesis on astronomical grounds was D.C.B. Whittet of Preston Polytechnic. His argument was based on spectroscopic measurements of the amounts of critical elements in space. The observations imply that carbon, nitrogen, and oxygen — the building blocks of organic molecules — are found mostly in atomic form in the low-density interstellar gas, and not in solid particles.

A more crucial objection concerns the element phosphorus — an integral part of nucleic acid chains. For every 10 carbon atoms present in DNA or RNA there must be 1 phosphorus atom on average. But phosphorus is 100 times less common in space, with 1,000 carbon atoms to every phosphorus atom. Although life in isolated concentrations of phosphorus is not ruled out (indeed, Earth's surface is just such a concentration), the idea that bacteria are widespread in space is difficult to reconcile with the cosmic shortage of phosphorus.

The remainder of the discussion centered chiefly on identifications of various crucial spectral features attributed to some constituent of the grains. Greenberg pointed out that an apparent ultraviolet absorption at 2800 Angstroms, claimed as evidence for interstellar proteins, is in fact nonexistent and resulted from a saturation effect in the detectors on board the International Ultraviolet Explorer satellite. (Hoyle and Wickramasinghe had obtained an embarrassingly good fit to the spurious spectrum with laboratory data for an amino acid.)

The infrared absorption at 3.4 μm was the subject of much debate, as this is the wavelength at which the carbon-hydrogen bonds present in any organic molecule display vibrational transitions. The fit obtained by Hoyle and Wickramasinghe with *E. coli* is remarkable, but it is not unique, according to H.W. Kroto of Sussex University. Kroto, a chemist, emphasized that no laboratory spectroscopist would be content to make an identification on the basis of a single spectral feature such as this, no matter how close the fit was.

Indeed, the observations could probably be matched with a large number of different organic molecules. D.A. Williams of UMIST showed that hydrogen atoms bonded to the surface of graphite grains also produce an equally good fit. New astronomical data showing 3.4 μm absorptions were presented by I. Butchart of Preston Polytechnic. He made his observations in collaboration with Whittet and Greenberg using a recently commissioned grating spectrometer at the United Kingdom Infrared Telescope in Hawaii. The new spectra show less structure in the 3.4 μm absorption than was previously found in data obtained under inferior conditions and at poorer resolution, which makes the bacterium fit less convincing.

In summary, the hypothesis that bacteria are widespread in interstellar space seems to be on shaky ground. The spectral features on which the model depends are in one case erroneous, in another ambiguous. More research is required to fully exploit the information available in other parts of the spectrum. Both the prevailing conditions in space and the availability of crucial elements place severe limits on the abundance of biological materials in space. However, the possibility that life forms might survive in limited quantities in comets is not ruled out on the basis of the current evidence. We await the return of Halley's Comet in 1986 with bated breath. *D.C.B. Whittet.*

Sundial Is Accurate to 15 Seconds

Most sundials are just about accurate enough to keep people from being late for lunch. A recent addition to the sundial at St. Mary's College in St. Mary's City, Maryland, will enable passers-by to set their watches to within 15 seconds of Eastern Standard Time — provided the Sun is shining, of course!

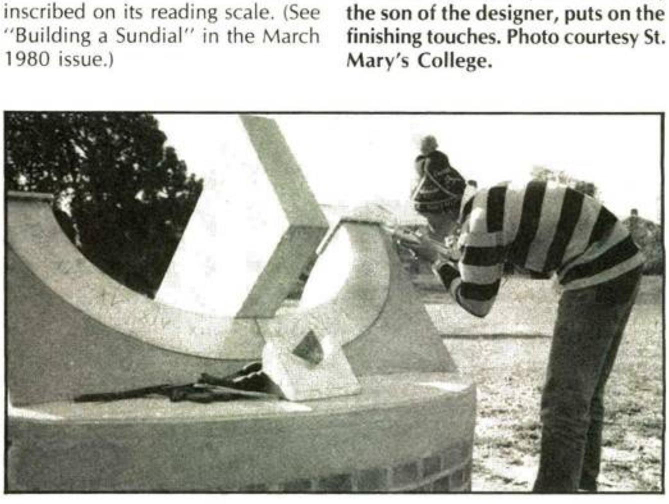
This very accurate sundial has a unique combination of features. It is an equatorial sundial (as opposed to the much better known vertical or horizontal type), it is large (six feet in diameter), and, most significantly, it has an equation-of-time curve inscribed on its reading scale. (See "Building a Sundial" in the March 1980 issue.)

The sundial was originally constructed in 1979 as a project in a summer school class. Initially, it indicated apparent solar time to within two minutes. The latest addition to the sundial makes it a lot more accurate: it is an engraved aluminum plate with many straight and curved lines designed to compensate for the several factors that make apparent solar time different from clock time.

One important correction follows from the fact that the dial's local time is different from "zone time" — few of us live exactly on the standard meridians for each time zone. Since Eastern Standard Time is the time at 75° west longitude, the St. Mary's dial had to be adjusted to account for the fact that St. Mary's City is 1° 26′ west, or behind, the Sun time seen at the 75th meridian. At noon Eastern Standard Time, the St. Mary's sundial also reads noon — that is, it's scale has been carefully designed to read that shadow as noon. When the Sun is directly over St. Mary's City — at *local* noon — no shadow is cast and a careful reading of the sundial shows it to be 12:05:44 p.m. EST.

That is, of course, if you know how to read the curve — and this is where the equation-of-time correction enters the picture. The shadows cast by the Sun at any given time each day have different lengths because the real Sun moves at a different rate across the sky than the fictitious "mean Sun" used in computing clock time. (See "Clocks and Calendars in Astronomy" in the January 1984 issue.) The dial's ingenious new scale compensates for this varying movement; without it, the reading could be as much as 16 minutes off.

A new addition to this sundial makes it read Eastern Standard Time to within 15 seconds; Bruce Merritt, the son of the designer, puts on the finishing touches. Photo courtesy St. Mary's College.



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April 20-22
Third Annual Conference on Space Development, San Francisco, California, sponsored by the L-5 Society. Contact: Charles Curley, Third Annual Conference on Space Development, 1275 Fourth St. #242, Santa Rosa, CA 95404. Phone (707) 538-1227.

April 28
Dedication of 3-meter Radio Telescope, Custer Institute, Southold, Long Island, New York. Workshops on amateur radio astronomy and star party. Contact: Tom Carey, Vanderbilt Planetarium, Centerport, NY 11721.

May 5
Astronomy Day. For more information, contact: Gary Tomlinson, Astronomy Day Coordinator, Astronomical League, Chaffee Planetarium, 54 Jefferson S.E., Grand Rapids, MI 49503. Phone (616) 456-3985. The Astronomical Association of Northern California hosts Astronomy Day on April 7.

May 23-25
IAPPP Big Bear Symposium, Camp Oaks, Big Bear Lake, California (same place as Riverside Telescope Maker's Conference). Contact: The Rev. Donald L. Rohe, 957 West Marshall Blvd., San Bernardino, CA 92405. Phone (714) 383-4731 or (714) 883-7923.

May 25-28
Riverside Telescope Maker's Conference, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Ave., Riverside, CA 92505.

May 30-June 3
Texas Star Party, Fort Davis, Texas. Contact: TSP '84, Dept. A, 128 N. Commerce, Burleson, TX 76028.

June 8-9
14th Annual Apollo Rendezvous and Telescope Fair, Dayton, Ohio. Sponsored by the Miami Valley Astronomical Society and the Dayton Museum of Natural History. Contact: Chairmen, Apollo Rendezvous, P.O. Box 287 Dabel Branch, Dayton, OH 45420.

June 11-13
Society of Amateur Radio Astronomers 1984 Symposium, National Radio Astronomy Observatory, Green Bank, West Virginia. Contact: Bob Patterson, 1548 Bell Flower Ct., Stone Mountain, GA 30088.

June 19-23
Southeastern Planetarium Association Annual Conference, Bradenton, Florida. Hosted by the Bishop Planetarium. Contact: John Hare, Director, Bishop Planetarium, 201 10th St. W., Bradenton, FL 33505. Phone (813) 746-4132.

June 22-24
Convention of the Mid-States Region of the Astronomical League, Washington University, St. Louis, Missouri. Contact: Convention Chairman, Stephen Best, 6943 Amherst Ave., University City, MO 63130; Papers Chairman, Mark Jones, 621 Parker Dr., Ballwin, MO 63011.

June 29-30
Burke Lake Telescope Meet, Burke, Virginia. Sponsored by the Northern Virginia Astronomy Club. Contact: John S. Huggins, 5608 Flag Run Dr., Springfield, VA 22151.

June 30
Northeast Regional Astronomical League Convention, Sperry Observatory, Cranford, New Jersey. Sponsored by Amateur Astronomers, Inc. Contact: Roger Tuthill, (800) 223-1063 (toll-free).

July 7-12
Joint Meeting of the Astronomical Society of the Pacific and the Western Amateur Astronomers, University of California, Santa Cruz, California. Contact: Summer Meeting, A.S.P., 1290 24th Ave., San Francisco, CA 94122.

July 10-14
Case for Mars II, Boulder, Colorado. A workshop on the future of manned missions to Mars, sponsored by the Mars Institute of the Planetary Society, the Boulder Center for Science and Policy, and the University of Colorado Space Interest Group. Contact: Case for Mars, P.O. Box 4877, Boulder, CO 80306.

July 12-14
Microcomputers in Astronomy II, Fifth annual IAPPP-Fairborn Symposium, Fairborn, Ohio. Contact Russell M. Genet, Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.

July 16-24
Spaceweek '84. Programs in many cities need your help. Contact: Spaceweek National Headquarters, P.O. Box 58172, Houston, TX 77258.

July 16-24
Florida Spaceweek '84. State-wide celebration of the 15th anniversary of the Apollo 11 Moon mission. Contact: Florida Spaceweek Committee, 993 Macco Rd., Cocoa, FL 32927.

July 16-August 3
Astronomy Institute for Pre-College Teachers, Austin, Texas. Contact: Mary Kay Hemenway, Department of Astronomy, University of Texas, Austin TX 78712. Phone (512) 471-4461.

July 20-31
International Workshop on Astrophotography, Oteppe, Belgium. Limited to young amateur astronomers ages 16-24. Contact: Luc Vanhoeck, Belgian Astronomical Association (VVS) Section Astrophotography, Elsbos 16, B-2520, Edegem, Belgium.

July 28
Stellafane, Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.

July 28
Ohio Turnpike Astronomers Association Convention, Hiram College, Hiram, Ohio. Sponsored by the Cuyahoga Astronomical Association. Contact: Gary Kader, 2580 Northglen Dr., Westlake, OH 44115.

August 1-4
ALCON '84, National Convention of the Astronomical League, Carroll College, Waukesha, Wisconsin. Hosted by Milwaukee Astronomical Society. Contact: ALCON '84, P.O. Box 275, Mequon, WI 53092.

August 1-4
Astromart '84, an astronomy equipment fair held simultaneously with ALCON '84. Carroll College, Waukesha, Wisconsin. Hosted by ASTRONOMY Magazine. Contact: Dana-Lynne Terry, Advertising Coordinator, ASTRONOMY Magazine, P.O. Box 92788, Milwaukee, WI 53202. Phone (414) 276-2689.

August 6-10
Spitz Space Systems' Summer Institute in Planetarium Education, Chadds Ford, Pennsylvania. Contact: 1984 Planetarium Summer Institute, Spitz Space Systems, Inc., Rt. 1, Chadds Ford, PA 19317.

August 9-12
Convention of the Southeast Region of the Astronomical League, Pensacola, Florida. Co-hosted by Escambia Amateur Astronomer's Association and the University of West Florida. Contact: Merry E. Wooten, 6235 Omie Circle, Pensacola, FL 32504.

August 17-18
Near-IR and Solid-State Photometry Symposium, Lowell, Michigan. Hosted by IAPPP and Optec. Contact: Russell M. Genet, Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.

August 24-26
Connecticut River Valley Astronomers' Conjunction, Northfield Mountain Center, Northfield, Massachusetts. Contact: Jack Megas, 311 Surrey Rd., Springfield, MA 01118.

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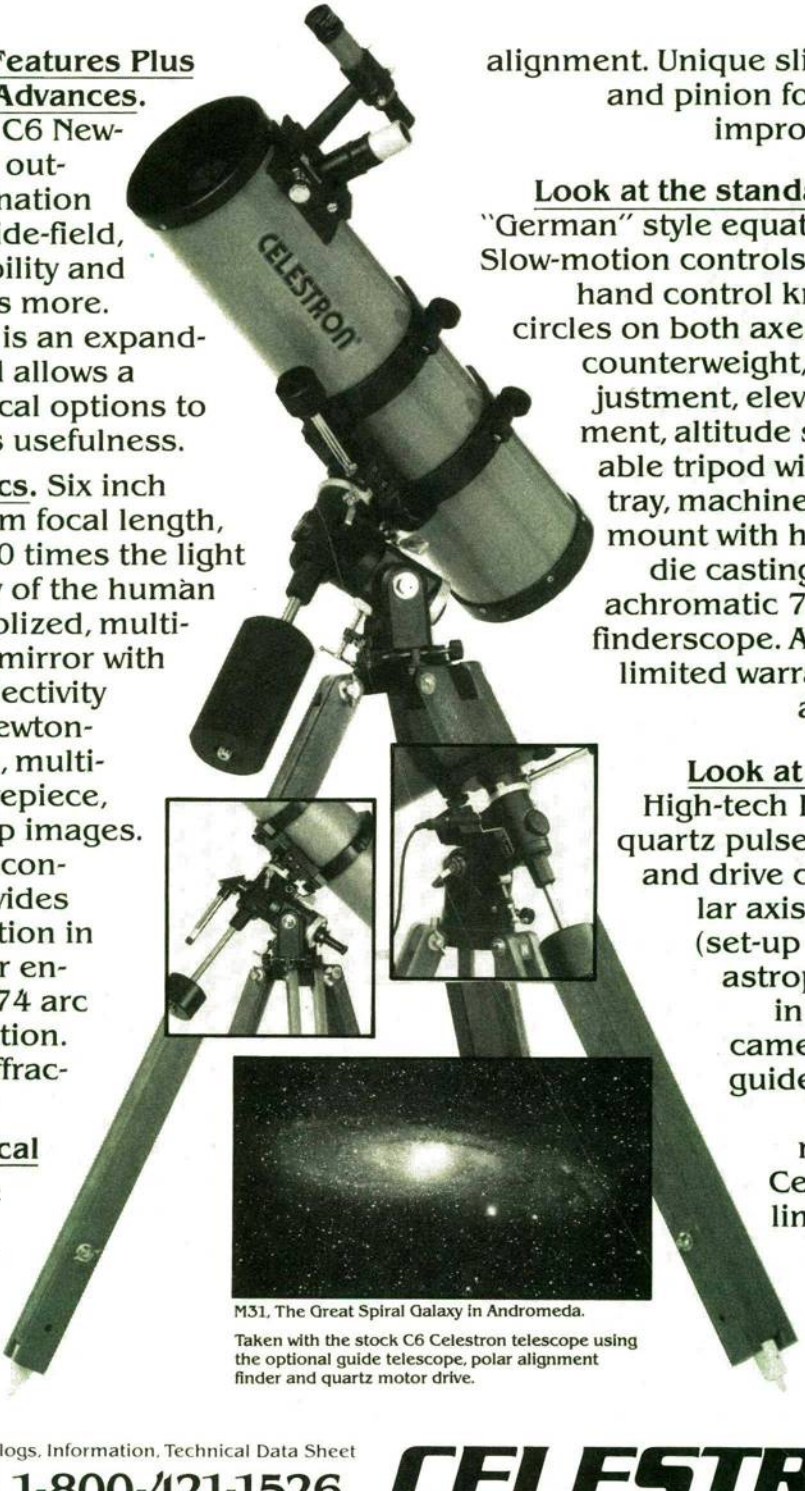

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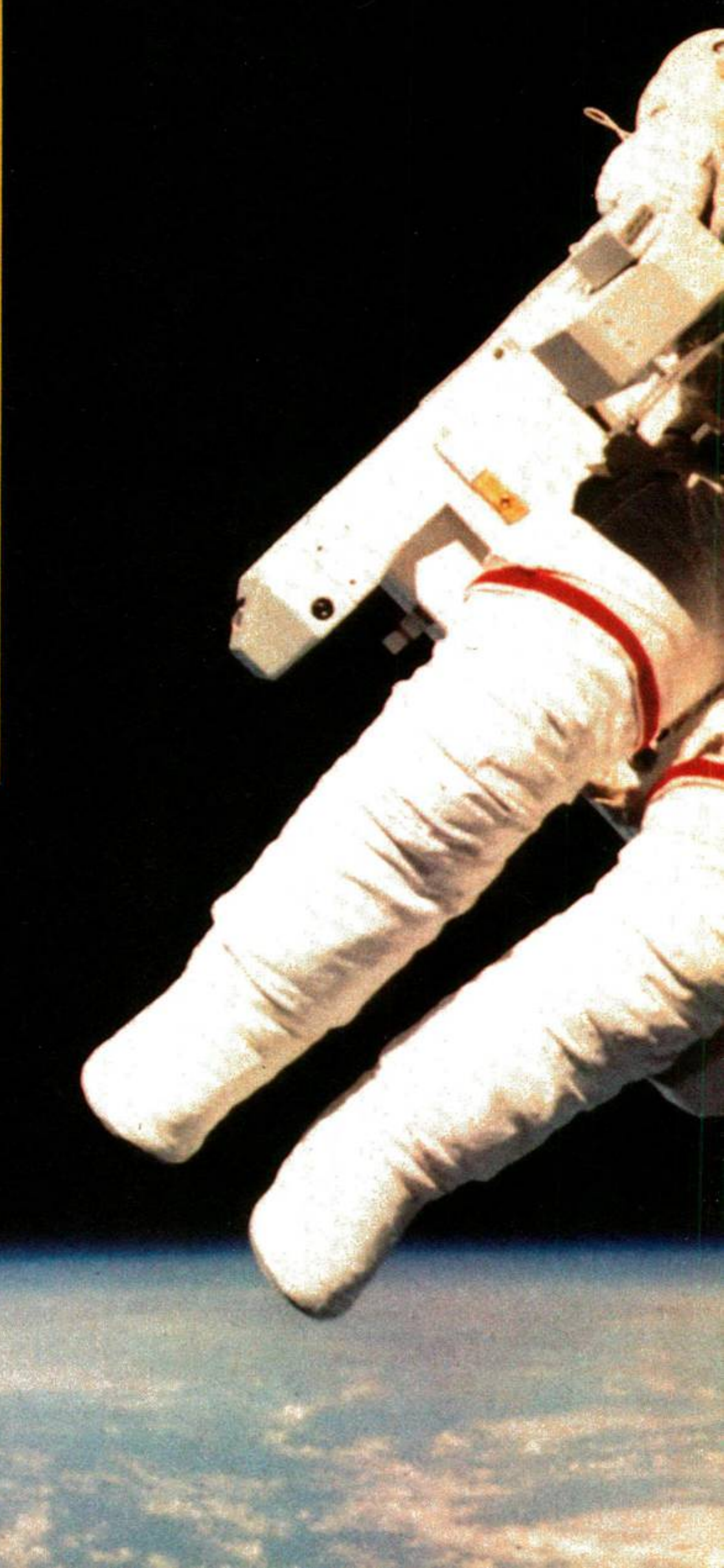
From 55 meters out, McCandless photographed *Challenger* above Earth's mottled limb during his test of the MMU. Astronaut Robert Stewart, who later donned the same MMU, floats beneath the "forearm" of the Shuttle's Remote Manipulator.

Indonesia's Palapa B-2 satellite floats out of *Challenger*'s payload bay. The satellite's booster rocket later failed, throwing it into a useless orbit similar to that of Westar-VI, the other satellite lofted during this mission.



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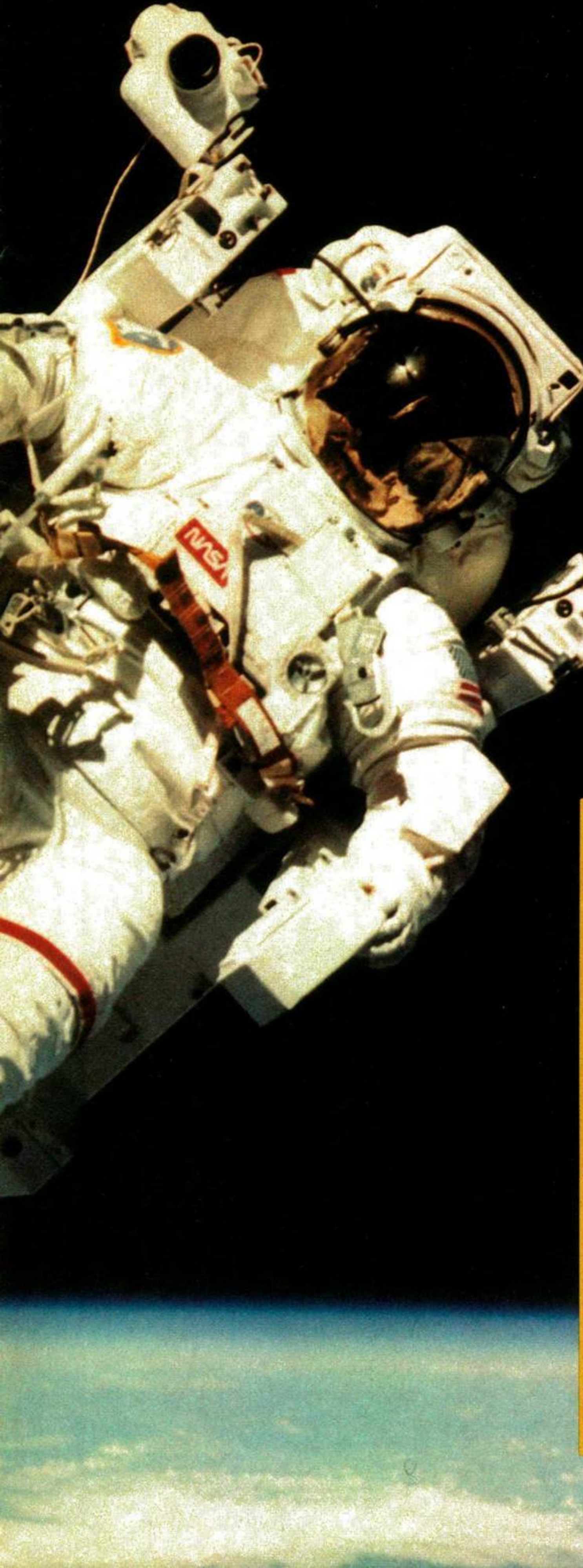
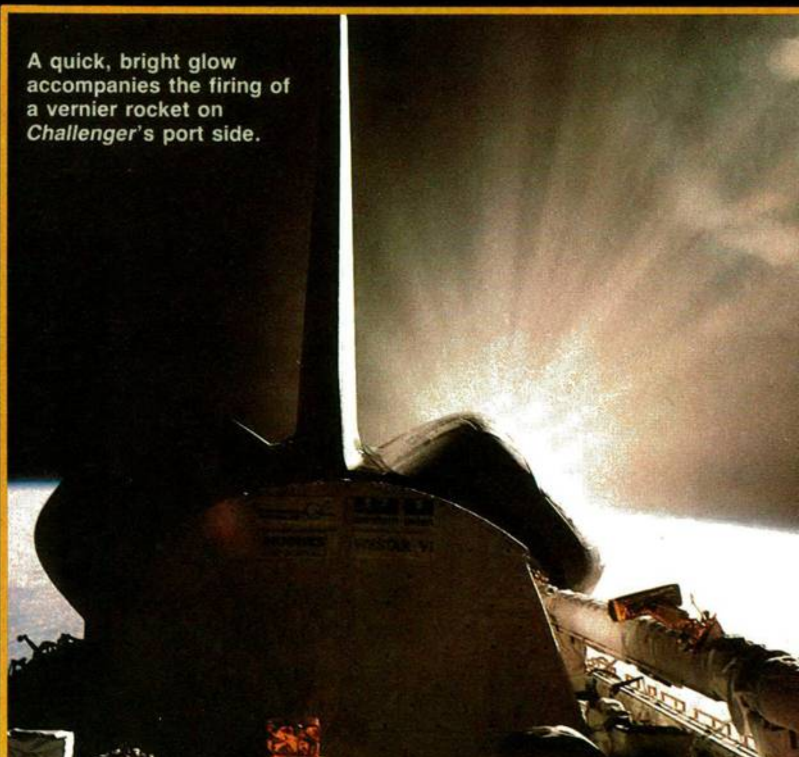
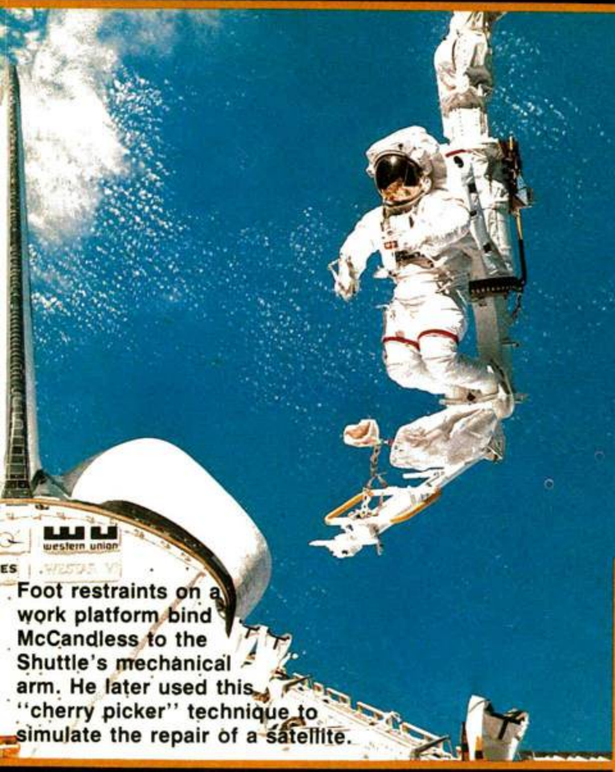


Astronaut Bruce McCandless hovers near the Space Shuttle *Challenger* during his test of the nitrogen-propelled Manned Maneuvering Unit (MMU) — the first free-flying "space walk."



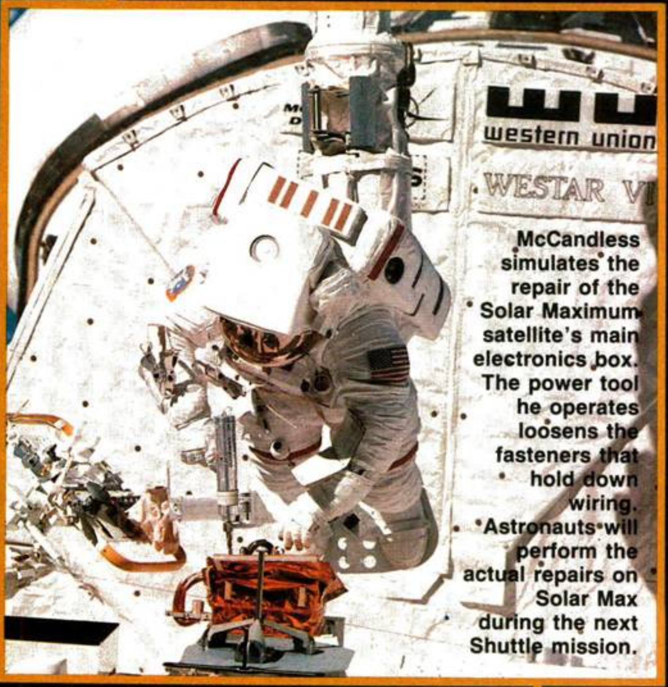
A quick, bright glow accompanies the firing of a vernier rocket on *Challenger*'s port side.

NASA photos.



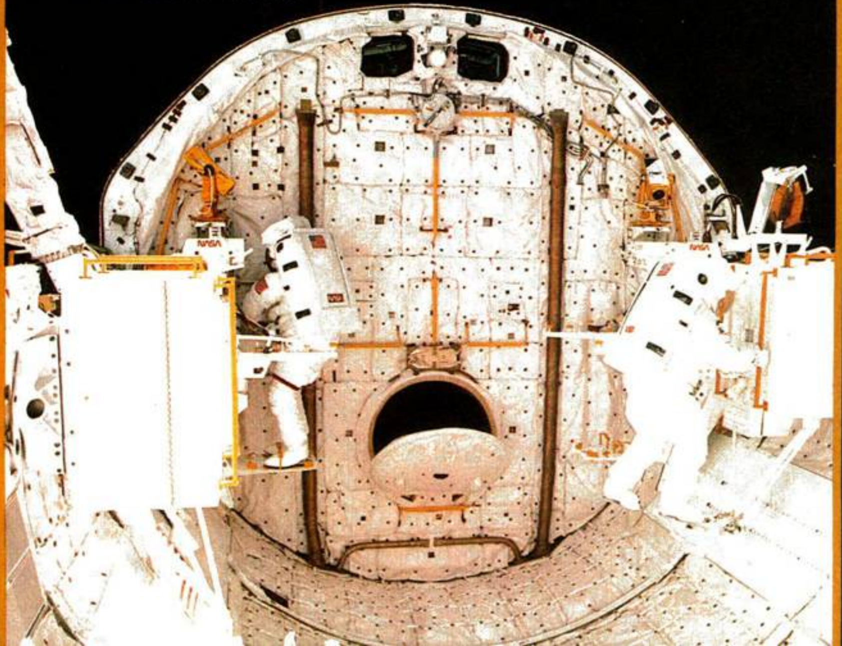
Foot restraints on a work platform bind McCandless to the Shuttle's mechanical arm. He later used this "cherry picker" technique to simulate the repair of a satellite.

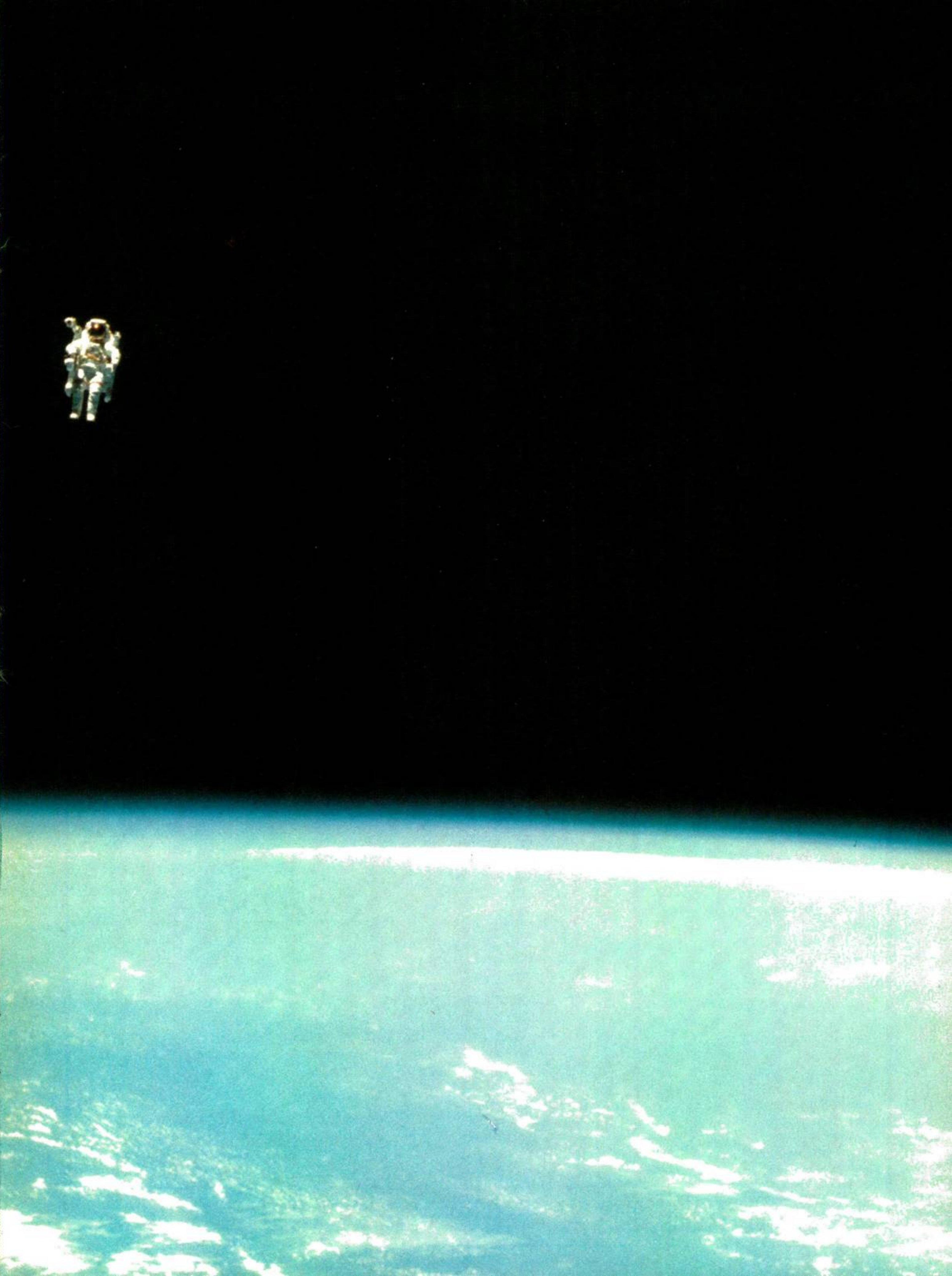
Astronaut Robert Stewart jets away from *Challenger*. Overleaf: McCandless jetted out to a distance of 90 meters.



McCandless simulates the repair of the Solar Maximum satellite's main electronics box. The power tool he operates loosens the fasteners that hold down wiring. Astronauts will perform the actual repairs on Solar Max during the next Shuttle mission.

Bruce McCandless and Robert Stewart work in the forward section of *Challenger*'s cargo bay. McCandless, left, stands on an MMU flight support station; Stewart works near the equipment stowage assembly of the second station.





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WANTED — Author looking for contact with anyone involved with the X-15 Research Aircraft program. Also, anyone else who has any information/photographs on the X-15. Contact Larry Evans, 32221 Alipaz #123, San Juan Capistrano, CA 92675.

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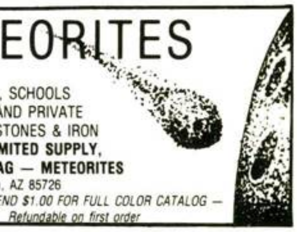

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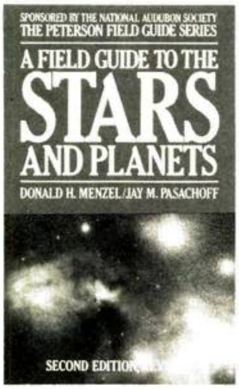

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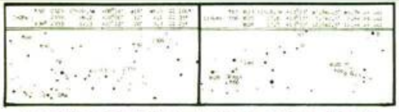

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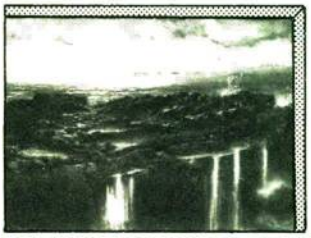

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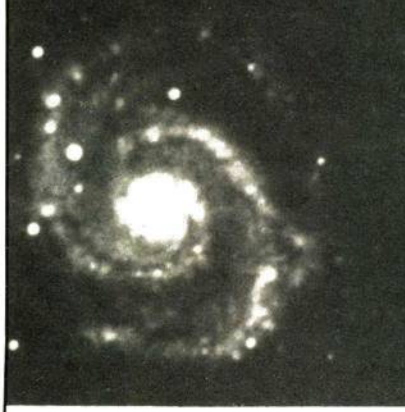

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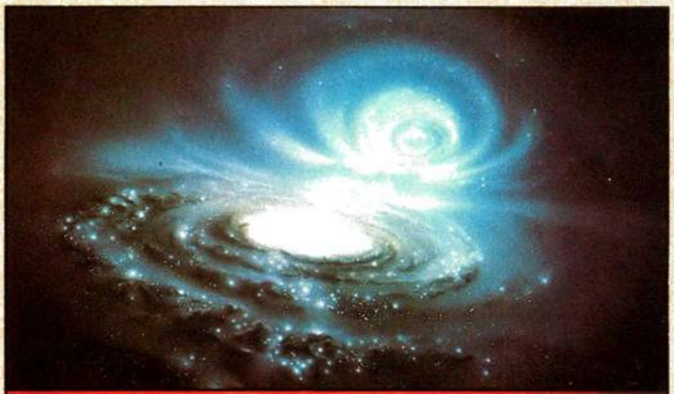

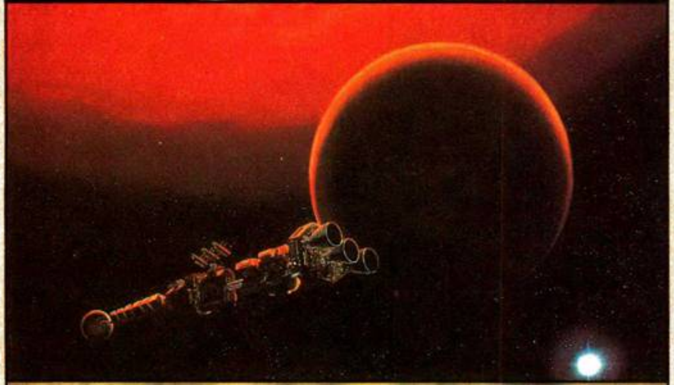

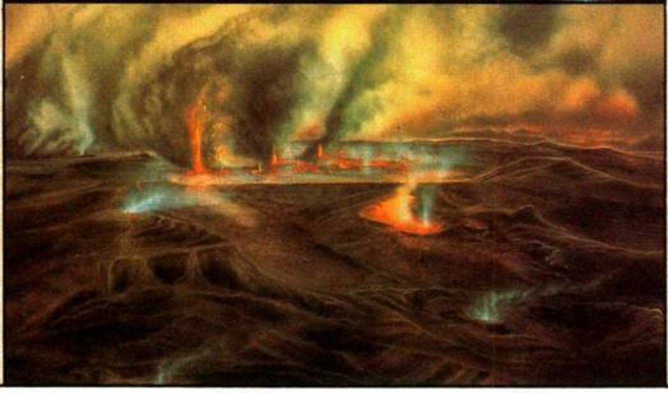

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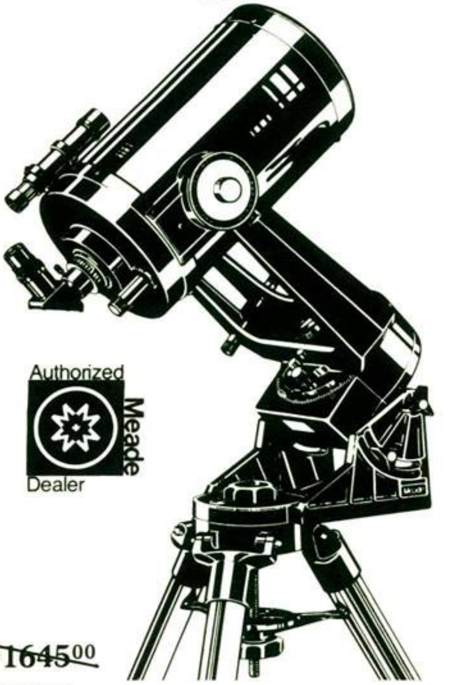

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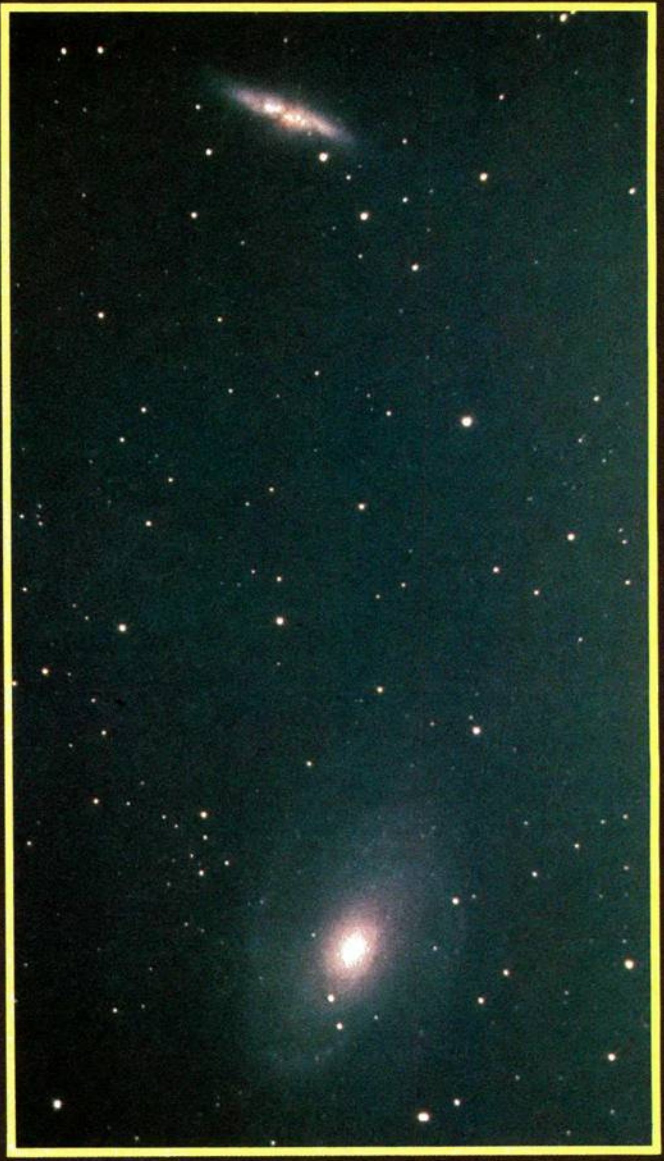
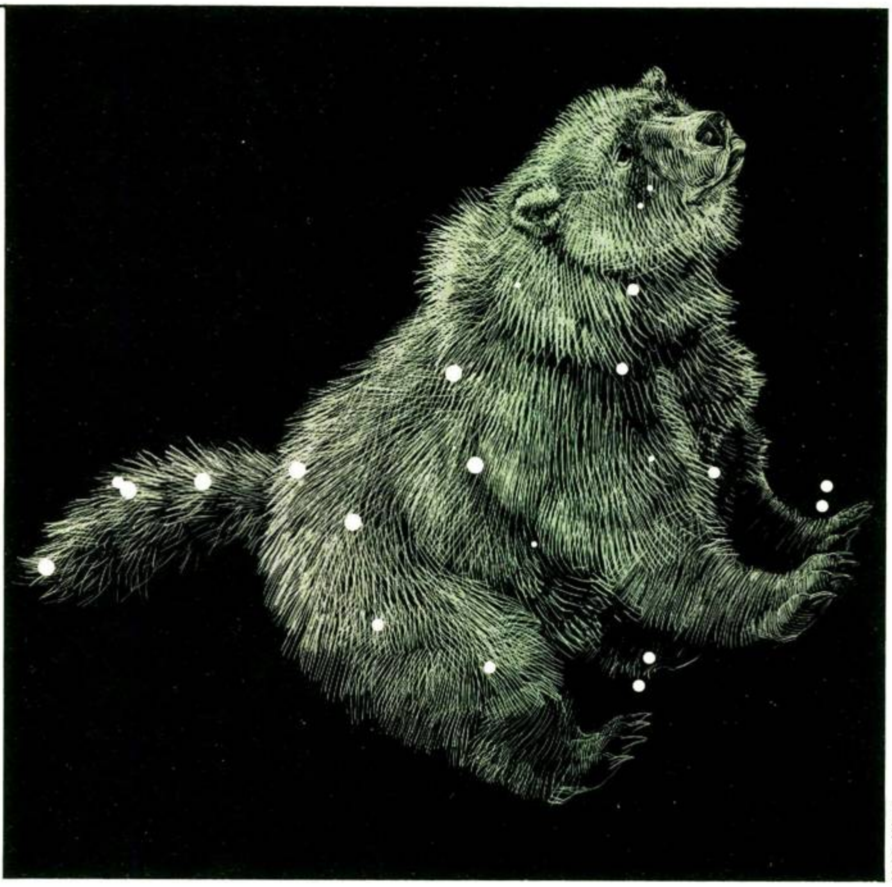


Above: NGC-2841 is an Sb-type spiral galaxy that has had three supernovae recorded in it — in 1912, 1957, and 1972. Photo by Martin Germano. Above right: M-81 and M-82 form a pretty pair in a low-power field of view. M-81 is a classic Sb-type spiral, while M-82 is an intriguing irregular. Photo by Jack Newton. Below: Another low-power pair is the Owl Nebula (M-97), a planetary nebula, and its edge-on spiral galaxy neighbor, M-108. Photo by Ronald Royer. Below right: M-101 is a large, open spiral galaxy that has also had several supernovae, in 1909, 1951, and 1970. A dim blur in small scopes, it displays bright knots in an amorphous field with instruments 12 inches or more in aperture. Photo by K.A. Brownlee.

Ursa Major

Ursae Majoris
UMa



Keith Ward

The large spring constellation **Ursa Major**, the Great Bear, is best known for the bright pattern of seven stars that forms the Big Dipper asterism. These stars do not appear together in the sky by chance; they are members of a related group of stars called the **Ursa Major Moving Cluster**, the nearest open star cluster. Consisting chiefly of main sequence stars of type A0 through K3, the cluster occupies an ellipsoidal volume of space about 10 parsecs long and 6 parsecs wide. Some 17 stars — including Alpha (α) Coronae Borealis — are probable members. The group lies about 25 parsecs distant.

The most observed of these stars is **Mizar** (Zeta [ζ] Ursae Majoris), perhaps the most popular double star in the entire sky. Mizar is the middle star in the Dipper's handle and with its little neighbor Alcor — some 11.8′ away in position angle 72° — has served as a test of naked-eye vision for centuries. Should you split the two stars unaided by optical instruments, you can rest assured your eyesight is in good shape. Alcor is not physically associated with Mizar; the stars constitute a mere optical double. A telescope, however, shows that Mizar itself is composed of twin white stars. The two stars, which are gravitationally bound, shine at magnitudes 2.5 and 4.0; they are separated by 14.4″ in p.a. 151°, and each has a spectral type of A2.

Another double star in Ursa Major has the distinction of being the only non-"nebular" Messier object. This is **M-40**, one of Messier's biggest mistakes: the astronomer Johannes Hevelius had recorded a nebula at the position in 1660; Messier observed only two faint stars close together but nevertheless included the entry in his catalog of nebulous objects. The double star, which more recently acquired the name Winnecke 4, has magnitudes of 9.0 and 9.3, a separation of 50.1″ in p.a. 83°, and a primary star spectrum of G0. This double lies just 70′ northeast of 70 Ursae Majoris, and the faint galaxy NGC-4290, a barred spiral of 13th magnitude, lies nearby. This galaxy could not have been recorded as Hevelius' nebulosity in 1660, however.

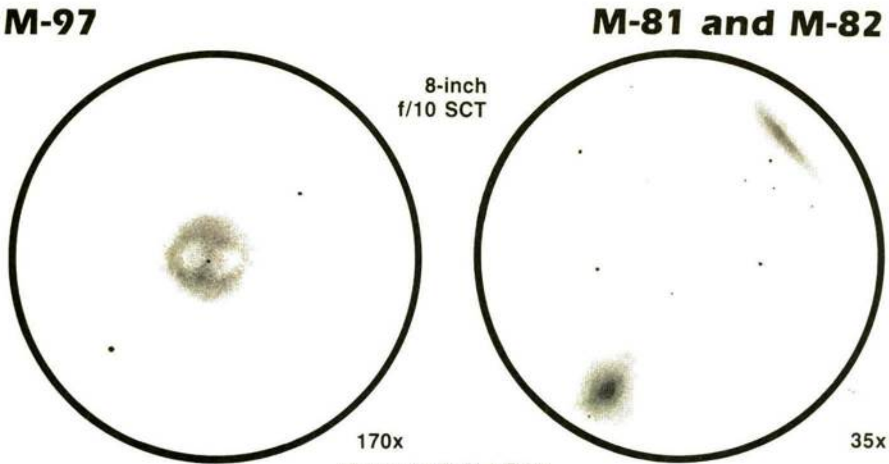
The star **R Ursae Majoris** is a fine example of a long-period variable; it fluctuates in brightness slowly and methodically between magnitudes 6.7 and 13.4 over a 302-day period. In 1853 the English astronomer N. Pogson found that this star varies in luminosity. It is a pulsating red giant about 450 parsecs distant and is receding at a rate of 13 kilometers per second. By observing R UMa's brightness with respect to nearby stars every couple of weeks, after a year's observing, you'll be able to draw a graph of the star's light curve.

Ursa Major is not well-known for its stars, but rather for the hordes of galaxies that lie within its boundaries. Looking at the Big Dipper, we are peering out through a thin part of the Milky Way's disk — toward the north galactic pole — which minimizes the Galaxy's dusty interference and reveals bright spirals and barred spirals.

A group of fine galaxies surrounds the bright Sb spiral **M-81** (NGC-3031), one of the best handful of galaxies in the sky. M-81 covers a sky area of 18.0′ x 10.0′ and shines at magnitude 7.9, making it visible in finderscopes. It is the primary member of the M-81 group, a cluster of about a dozen galaxies, which at a distance of 2.3 megaparsecs (Mpc), may be the nearest group of galaxies to the Local Group. **M-82** (NGC-3034), an edge-on irregular galaxy of high surface brightness, and **NGC-2976**, a small, bright Sc/Sd galaxy with an irregular spiral pattern, are also members. M-82 has an integrated magnitude of 9.3 and measures 8.0′ x 3.0′ across, whereas 2976 glows at magnitude 10.9 and spans only 3.4′ x 1.3′. In 20x80 binoculars, M-81 and M-82 appear in a single field of view, separated by 38′. In a 4-inch telescope at low power, M-81 appears as a bright oval haze without detail and M-82 shows a slim grey needle of uniform light. An 8-inch scope with high power reveals a huge low-surface-brightness halo of nebulosity around M-81 and dusty patches crossing M-82's sharp surface. M-82 shows a highly condensed nucleus at high power. The little galaxy NGC-2976 lies 84′ south-southwest of M-81; it displays a bright oval without detail in an 8-inch scope.

Another Messier galaxy in Ursa Major, about 5.5° east of Mizar, is **M-101** (NGC-5457), a giant Sc-type spiral measuring 22.0′ x 20.0′ across and radiating at magnitude 8.2. Since it is face-on to our line of sight, M-101 has a low surface brightness, which makes small parts of it appear dim. On a dark, crisp night, an 8-inch telescope shows a bright

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.



Sketches by David J. Eicher

condensed core surrounded by a halo of hazy nebulosity, which fills an entire low-power field and includes several knotty patches. Under ideal skies, small low focal ratio telescopes — coupled with wide field oculars — can reveal a weak spiral shape in the elusive halo of nebulosity. At a distance of 5 Mpc, M-101 is one of the closest spiral galaxies to our own spiral Milky Way.

About 2.4° southeast of Merak (Beta [β] Ursae Majoris) is the fine planetary nebula **M-97** (NGC-3587), commonly known as the Owl Nebula. This is one of only four Messier planetaries, and one of the faintest objects in the Messier catalog; it is, however, visible as a dim circular disk in 3-inch telescopes. The name Owl Nebula originated with Lord Rosse, who, over a century ago, first detected two dark patches superimposed on the face of the nebula. On photographs and with large telescopes, these patches resemble eyes staring from the inky blackness of space. Under good conditions an 8-inch telescope at high power can show the eyes, but a 12-inch telescope is normally required to see them normally. M-97's central star is a 14th magnitude object, making it elusive in anything less than 12-inch scopes. The Owl Nebula measures 203'' in diameter and glows at 12th magnitude. Just 48' northwest of the Owl Nebula lies the edge-on galaxy **M-108** (NGC-3556). Both objects fit neatly into low-power fields of view, the galaxy appearing as an 8' long streak of grey-green nebulosity. Its total magnitude is 10.7, giving it a fairly high surface brightness; thus it can withstand high magnification, where it sometimes shows tiny dark structures resembling those in M-82.

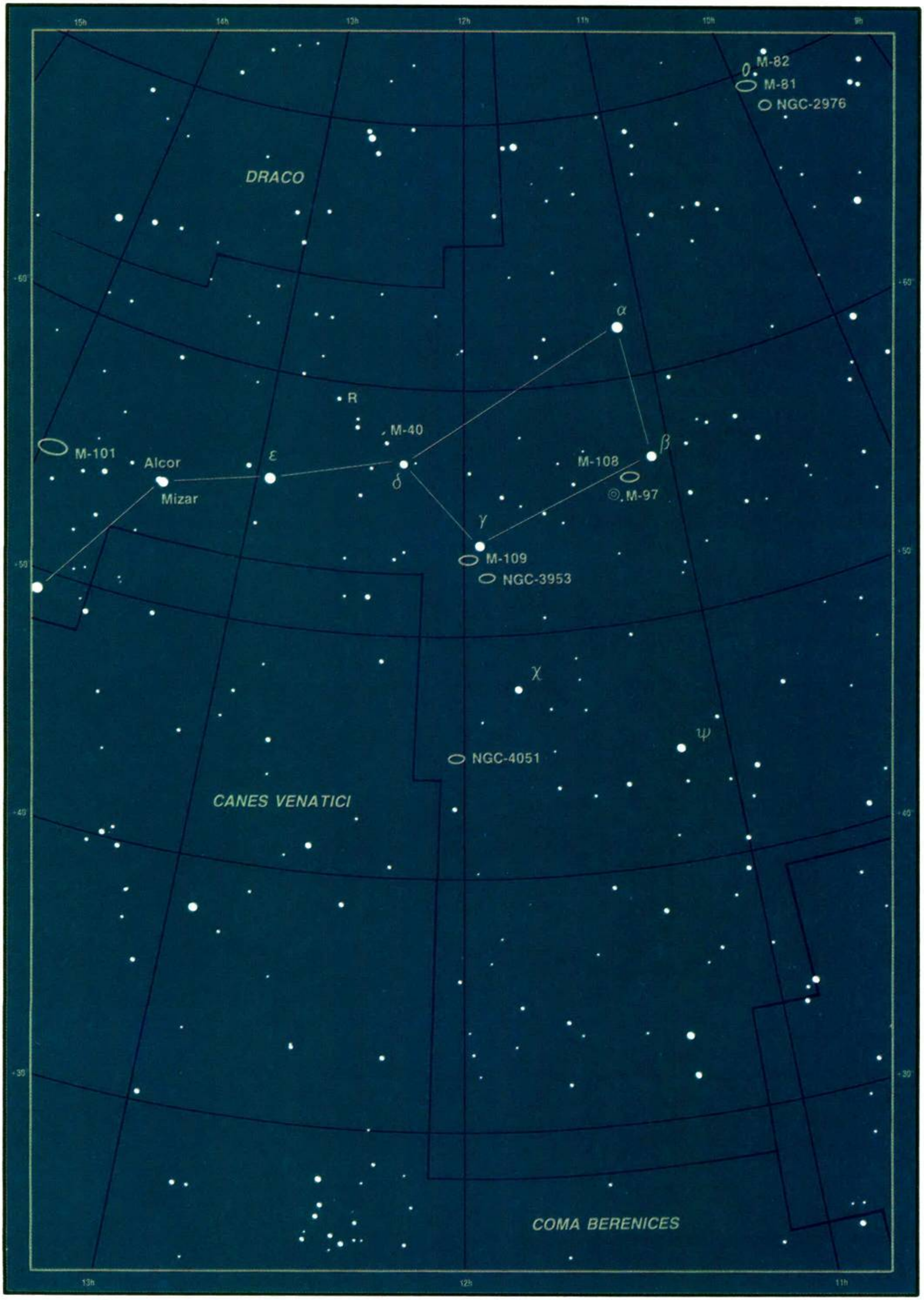
The bright, theta-shaped barred spiral **M-109** (NGC-3992) lies a mere 40' southeast of Phecda (Gamma [γ] Ursae Majoris), and is visible as a hazy nebulosity in the same low-power field. To best observe the galaxy, however, switch to higher magnifications and move the bright star well out of the field; this will eliminate the star's overpowering glare. With a 6-inch telescope you'll see a small sharp nucleus surrounded by a 6.4' x 3.5' area of mottled nebulosity. The galaxy's total magnitude is 10.6; it is bright enough that large telescopes begin to show hints of structure on nights of good transparency. Southwest of M-109 is another bright spiral, **NGC-3953**. This object measures 6.0' x 2.8' and shines at magnitude 10.8, making it easily visible as a small patch of grey light in a 2-inch refractor. Larger telescopes 6 and 8 inches in aperture reveal subtle low-surface-brightness nebulosity within the spiral, suggesting tightly wound spiral arms. Far south of the M-109/NGC-3953 area is the nice Sb/Sc-type spiral **NGC-4051**, renowned for its thick spiral arms, which are invisible to backyard telescopes. The galaxy, which shines at magnitude 10.9 and measures 4.2' x 3.0' in diameter, does show a condensed nucleus and faint outer haze under sufficiently dark skies.

Three fine galaxies inhabit the far western reaches of Ursa Major: **NGC-2841**, **NGC-3079**, and **NGC-3184**. NGC-2841 is large and bright, an easy target for binoculars and finderscopes. Its magnitude of 10.2 and dimensions of 6.2' x 2.0' make its surface brightness fairly high, which in turn makes it an impressive galaxy in small and large telescopes. It is a type Sb system with tightly wrapped multiple arms, which appear in backyard scopes as a mottled oval haze encapsulating a large bright central hub. Telescopes 6 inches in aperture show finely detailed dust patches on the outer parts of the haze under very good skies — these patches are routinely visible with 16-inch telescopes. The barred spiral NGC-3079 is a fine example of an edge-on galaxy, glowing at magnitude 11.2 and measuring a thin 8.0' x 1.0' across. Observationally it fits into the same class as M-82, but shows less detail. NGC-3184 is a type-Sc spiral measuring 5.5' x 5.5' and shining at magnitude 10.4; it lies in the field of Mu (μ) Ursae Majoris and shows as a low-surface-brightness haze surrounding a relatively bright core.

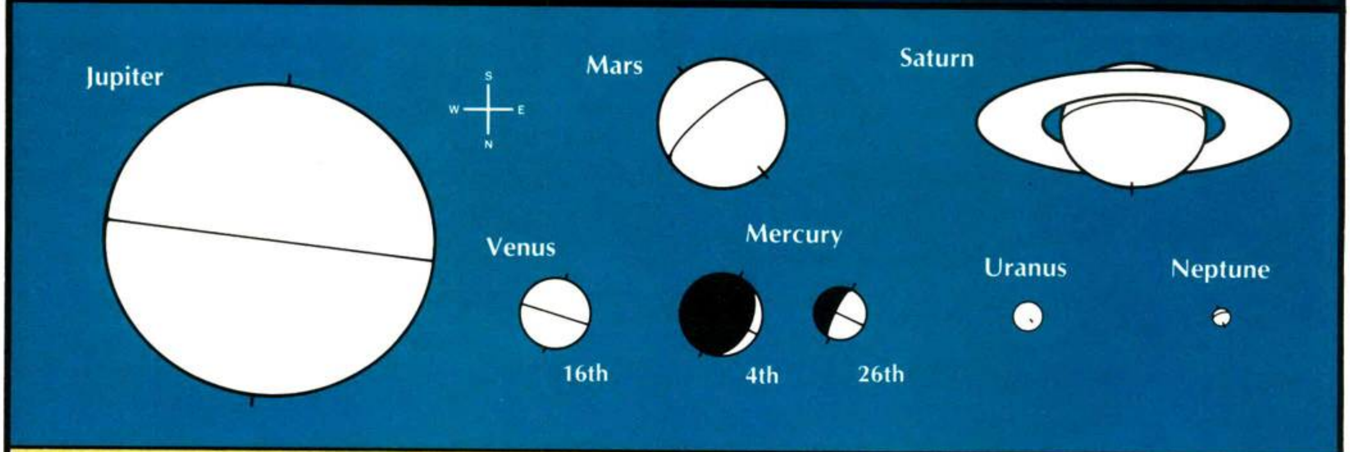
Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-2841		∮	9h 22m	+50°59'	10.2	6.2'x2.0'	Sb
NGC-2976		∮	9h 47m	+67°54'	10.9	3.4'x1.3'	Sc/Sd
NGC-3031	M-81	∮	09h 56m	+69°04'	7.9	18.0'x10.0'	Sa/Sb
NGC-3034	M-82	#	09h 56m	+69°42'	9.3	8.0'x3.0'	Ipec
NGC-3079		∮B	10h 02m	+55°43'	11.2	8.0'x1.0'	SBb
NGC-3184		∮	10h 18m	+41°25'	10.4	5.5'x5.5'	Sc
R UMa		LPV	10h 45m	+68°46'	6.7↔13.4	302d	
NGC-3556	M-108	∮	11h 12m	+55°41'	10.7	7.8'x1.4'	Sc
NGC-3587	M-97	■	11h 15m	+55°02'	12.0	180''	
NGC-3953		∮B	11h 54m	+52°20'	10.8	6.0'x2.8'	SBb
NGC-3992	M-109	∮B	11h 58m	+53°22'	10.6	6.4'x3.5'	SBb
NGC-4051		∮	12h 03m	+44°31'	10.9	4.2'x3.0'	Sb/Sc
Winnecke 4	M-40	★²	12h 22m	+58°05'	9.0,9.3	50.1''	
Mizar (ζ)		★²	13h 24m	+54°55'	2.5,4.0	14.4''	
NGC-5457	M-101	∮	14h 03m	+54°21'	8.2	12.0'x20.0'	Sc

H = Hubble classification type for galaxies

★²	*Double Star*
LPV	*Long Period Variable*
■	*Planetary Nebula*
∮B	*Barred Spiral Galaxy*
∮	*Spiral Galaxy*
#	*Peculiar Galaxy*

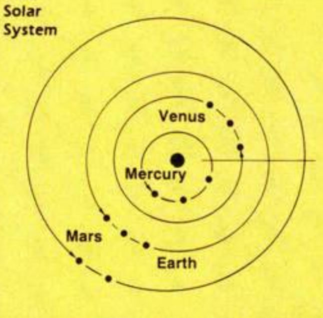

15h
14h
13h
12h
11h
10h
9h
M-82
M-81
NGC-2976
DRACO
+60°
α
R
M-40
M-101
Alcor
ε
Mizar
δ
β
M-108
M-97
γ
M-109
NGC-3953
+50°
χ
ψ
NGC-4051
CANES VENATICI
+40°
+30°
COMA BERENICES
13h
12h
11h

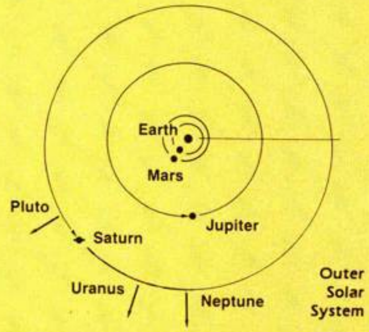
Planetary Data May 1984


Jupiter
S
W
E
N
Mars
Saturn
Venus
Mercury
Uranus
Neptune
16th
4th
26th

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.7	31.8′	—	1.01	—	—	40°48.8′	2h 34.4m	+15°08.2′
		15	−26.7	31.7′	—	1.01	—	—	54°21.3′	3h 28.8m	+18°54.8′
		31	−26.7	31.6′	—	1.01	—	—	69°44.1′	4h 33.2m	+21°56.6′
Mercury	☿	1	3.0	11.5″	7%	0.56	0.46	238°19.7′	26°48.0′	1h 43.0m	+ 9°37.0′
		15	0.9	9.0″	31%	0.74	0.46	277°08.8′	29°09.6′	1h 55.7m	+ 8°21.8′
		31	−0.1	6.6″	60%	1.02	0.40	329°01.5′	47°00.0′	3h 03.7m	+14°31.1′
Venus	♀	1	−3.9	9.9″	98%	1.68	0.73	11°20.1′	28°03.2′	1h 48.8m	+ 9°46.8′
		15	−3.9	9.8″	99%	1.71	0.72	33°40.8′	45°16.1′	2h 55.1m	+15°40.6′
		31	−3.9	9.7″	100%	1.73	0.72	59°19.5′	64°55.7′	4h 15.1m	+20°49.7′
Mars	♂	15	−1.9	17.5″	100%	0.53	1.54	232°41.6′	229°04.0′	15h 09.8m	−17°58.1′
Jupiter	♃	15	−2.5	43.6″	99%	4.51	5.24	274°19.6′	282°05.2′	18h 55.7m	−22°40.0′
Saturn	♄	15	0.1	18.6″	100%	8.87	9.86	223°27.0′	221°44.3′	14h 43.2m	−13°05.6′
Uranus	⛢	15	5.5	3.9″	100%	18.05	19.01	251°21.1′	251°46.2′	16h 41.2m	−22°15.7′
Neptune	♆	15	7.9	2.3″	100%	29.44	30.26	269°49.6′	270°27.2′	18h 05.1m	−22°13.4′
Pluto	♇	15	13.7	0.1″	100%	28.94	29.83	210°55.4′	209°37.5′	14h 16.9m	+ 4°43.9′

Inner Solar System


Venus
Mercury
Mars
Earth

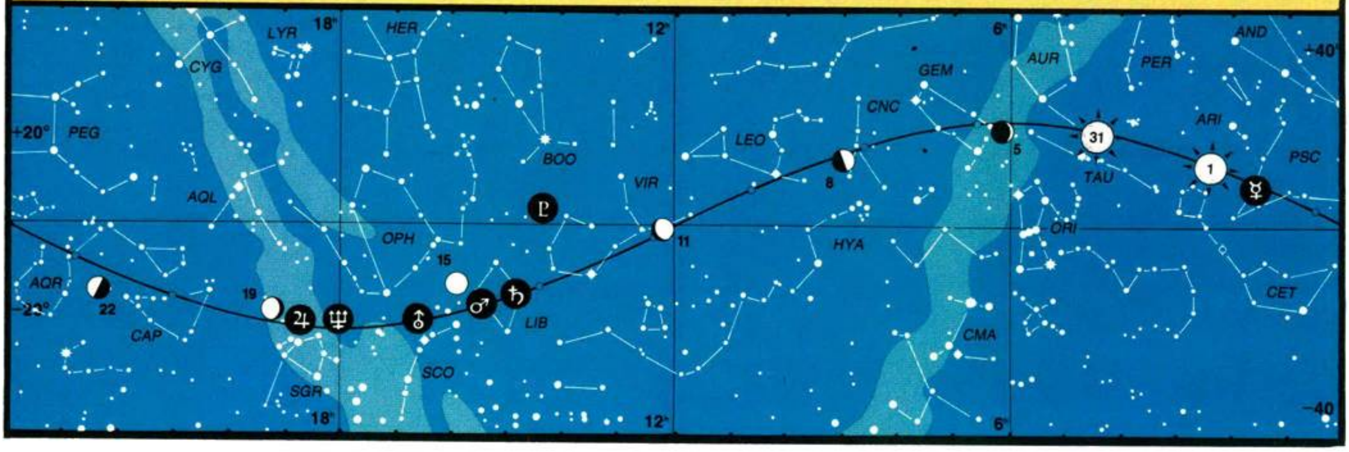

Earth
Mars
Pluto
Saturn
Jupiter
Uranus
Neptune

Outer Solar System

Moon Data

New Moon	May 1 at 3:45
First Quarter	May 8 at 11:50
Full Moon	May 15 at 4:29
Last Quarter	May 22 at 17:45
New Moon	May 30 at 16:48
First Quarter	June 6 at 16:42

Perigee: May 12 at 3:08 . . . . . 365,605 km.
Apogee: May 24 at 1:00 . . . . . 404,457 km.


LYR
18h
HER
12h
6h
AUR
AND
+40
CYG
GEM
PER
CNC
ARI
+20°
PEG
LEO
31
PSC
BOO
8
5
TAU
1
AQL
VIR
☿
♇
ORI
OPH
11
HYA
15
AQR
♄
CET
−20°
22
19
♃
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♂
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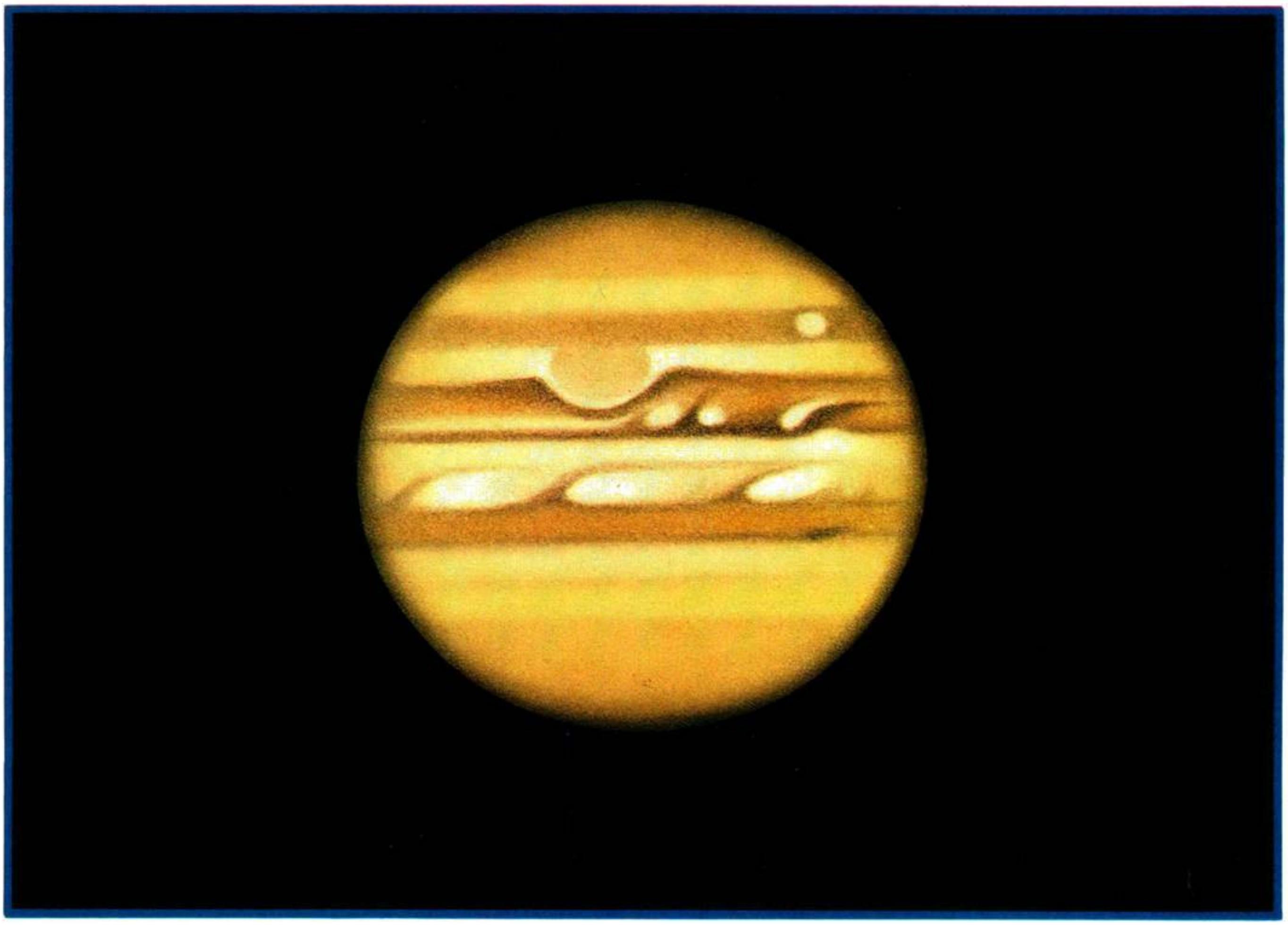
SGR
18h
12h
6h
−40



With an 8-inch reflector at 166x, Mark Daniels made the observations for this painting last June 15. He noted the Red Spot looked "dusky pink-grey."

Mercury

Although Mercury comes to greatest western elongation in the morning sky on May 19th, this is the year's worst elongation for observers in mid-northern latitudes. Reaching an elevation of only 2 or 3 degrees late in May, Mercury won't offer much to see. You'll do better to wait until the morning elongation in the middle of September.

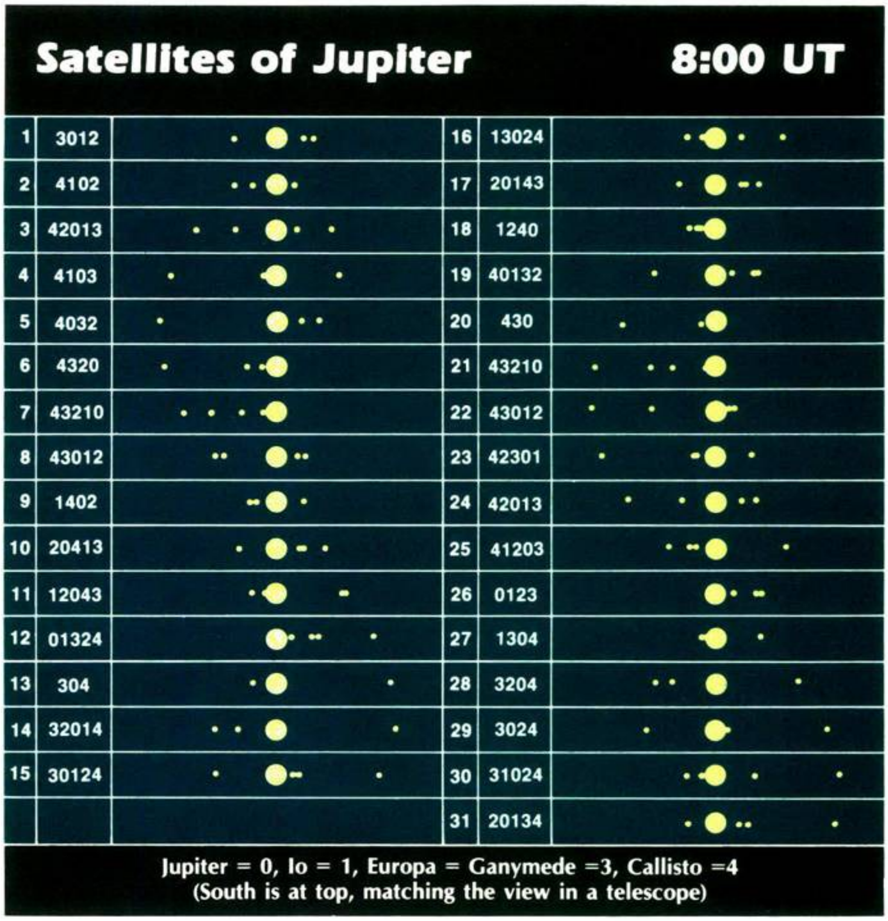
Venus

Now lost in the glow of light from the Sun, Venus can best be found in daylight by offsetting from the Sun (see last month's Backyard Astronomer). Or try looking for it during the annular eclipse on the 30th, when Venus will lie about 4° west of the Sun.

Moon

Besides creating an annular eclipse on the 30th (see the Eclipse Specials on pages 34 and 50 of this issue), the Moon also undergoes an eclipse of its own. At Full Moon on the night of May 14-15 (two weeks before the annular eclipse), the Moon will pass through the penumbra of the Earth's. At maximum eclipse, the Moon will be 83.2% into the penumbra.

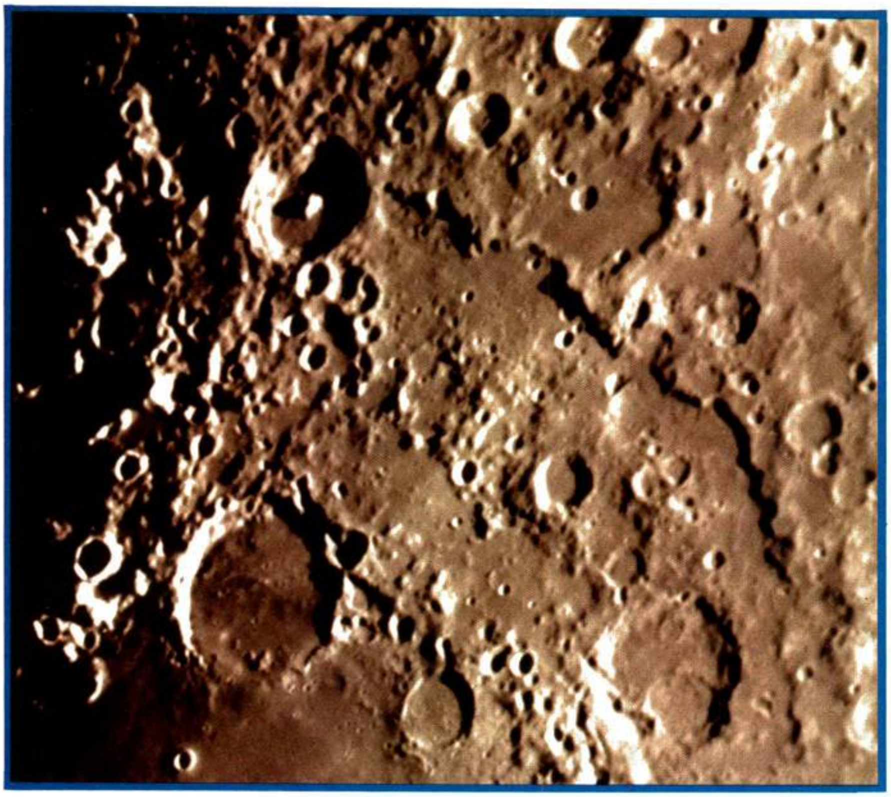
First contact with the penumbra is at



Satellites of Jupiter 8:00 UT

1	3012
2	4102
3	42013
4	4103
5	4032
6	4320
7	43210
8	43012
9	1402
10	20413
11	12043
12	01324
13	304
14	32014
15	30124
16	13024
17	20143
18	1240
19	40132
20	430
21	43210
22	43012
23	42301
24	42013
25	41203
26	0123
27	1304
28	3204
29	3024
30	31024
31	20134

Jupiter = 0, Io = 1, Europa = Ganymede =3, Callisto =4
(South is at top, matching the view in a telescope)



Right: Winner of the May Best Astro-Photo Award is Walt Hamler's shot of IC 5067, the Pelican Nebula, in Cygnus. He used an 8-inch f/5 Newtonian and a 45-minute exposure on 103a-F. Left: South of Mare Nectaris lie Fracastorius (bottom), Piccolomini (top), and the curving Altai Scarp. Photo by Jean Dragesco.

2:42 UT on the 15th, mid-eclipse is at 4:40, and last contact is 6:39. Penumbral eclipses don't show a lot — the modest darkening that occurs doesn't become visible until right around mid-eclipse — if then — and vanishes soon after. All you can hope to see is a slightly greyish cast on the southern lunar highlands when the eclipse reaches its maximum.

Mars

On the 11th of May, Mars comes to opposition; a week later on the 19th, it is at its closest to Earth for this apparition: 0.532 AU or 79,200,000 kilometers. Mars' disk will measure 17.6" of arc. If you've been watching it in your telescope for the past few months, you've seen it grow steadily larger and brighter. Experienced Mars-watchers say that visual observations work best when the planet is at least 6" of arc across; Mars will remain larger than that until late November.

The martian day is only some 37 minutes longer than the terrestrial day. Thus if you observe Mars at the same time each night, the longitude crossing the center of the disk lies some 9° to the east of the previous night's. By observing a short while over many nights, you'll eventually get a complete view of the martian surface markings.

Asteroids

1 Ceres (magnitude 8.8) is emerging from the Sun's glare in the morning sky. It lies along the Pisces/Cetus border. Its positions:

10th: 1h 30m 38s, +1° 12.8'
20th: 1h 44m 33s, +2° 32.5'

Ceres rises around 5 a.m. local daylight time at midmonth.

2 Pallas (10.2) is moving northeastward in Pegasus near the star Markab. Its positions:

10th: 22h 43m 44s, +7° 46.3'
20th: 22h 51m 53s, +8° 27.8'

Pallas rises about 2 a.m. local daylight time on May 15th.

3 Juno (9.9) is moving eastward from northern Orion into Gemini. Its positions:

10th: 5h 58m 8s, +14° 35.9'
20th: 6h 19m 54s, +14° 58.3'

Juno sets around 10 p.m. local daylight time in the middle of May.

4 Vesta (8.3) is moving eastward in Gemini somewhat to the north of Juno. Its positions:

10th: 6h 34m 43s, +24° 20.9'
20th: 6h 52m 9s, +24° 14.8'

Vesta sets around 10:30 p.m. local daylight time on May 15th.

For convenience in plotting their positions in a star atlas, all asteroid coordinates are for the epoch 2000.0.

Jupiter

Jupiter, the bright "star" north of the Teapot's handle in Sagittarius, is moving slowly retrograde during all of May. As detailed in Eye on the Sky, it has close conjunctions, with Nu^2 (ν^2) Sagittarii on the 17th and with Nu^1 (ν^1) on the 21st, which will be seen best at medium to low power.

Jupiter's moon system falls into two categories: the four that are easily visible in backyard scopes and the 11 or 12 others that aren't. The four Galilean moons are bright and easy to spot, but can you detect Amalthea (J5), the brightest of "the others"? Amalthea was found by E.E. Barnard in 1892; it has an average magnitude at opposition of 14.1. This would be within reach of scopes of 8 inches aperture if it were not for Jupiter's glare. Amalthea will certainly pose a severe challenge — it orbits just 2.55 Jupiter radii from the center of the planet and takes 11 hours 57 minutes to make one circuit. It will be at greatest eastern elongation on May 9th at 8:36 UT, May 19th at 7:42 UT, and May 29th at 6:48 UT. (It will also be there between these dates at times that are even multiples of its 11h 57m period.) Good luck!

Saturn

Saturn's family of moons has one outstanding member, Titan, at magnitude 8.3 and 16 others that range from magnitude 9.7 to 18.5. Titan orbits some 20 Saturn radii away from the planet and takes 15 days 22 hours 41 minutes for one orbit. In your telescope, the 5150 km diameter moon will look like just a dot of light — in fact, you'll probably take it for a star until you have watched enough nights to see that is is circling Saturn. Titan is at eastern elongations on May 7th and 23rd, at western elongations on May 15th and 31st.

Uranus

Greenish-grey and 3.9" in diameter, Uranus displays a soft round sixth-magnitude disk in a medium-power eyepiece. The planet is currently in Ophiuchus, about 5° northeast of Antares, Alpha (α) Scorpii.

Neptune

Softer, dimmer, and even more colorless than Uranus, Neptune has an eighth-magnitude disk only 2.3" across. It lies about a degree northeast of M-20, the Trifid Nebula, in Sagittarius. (Look for both Uranus and Neptune using the finder charts printed on page 83 of the January issue.)

Meteors

Three meteor showers peak early this month, one relatively strong and two minor. The strong shower is the Eta Aquarid, whose radiant is at 22.4h, 0°. Eta Aquarids are very swift (65 km/sec); from a good site you can expect to see about 20 per hour. The greatest activity will be around 7h UT on May 4th; the Moon is New and its light will not interfere. These meteors derive from Comet Halley and scientists are interested to see how their numbers fare as the comet returns.

May's two other showers are the Phi Bootids (radiant: 16h, +50°), which peak on the 1st and are very slow and sparse, and the Alpha Scorpiids (radiant: 16h, −23°), peaking around the same time and also slow and sparse. Both showers will produce but a few meteors an hour — though at least the Moon will be nearly New and the skies will be dark all night long for them.

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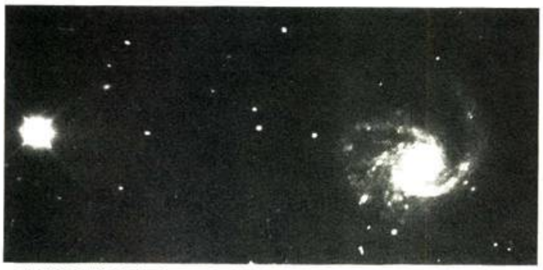
ASTROPHOTO OF THE MONTH



Spiral Galaxy NGC4254 (M-99) in Coma Berenices. The spiral arms of this lovely 10th magnitude galaxy can be seen in larger aperture telescopes. Photo by Dr. Jack Marling using a LUMICON EASY-GUIDER and 2415 film sensitized in a LUMICON Model 300 HYPER-KIT. 40 minute exposure, 24"f/6.5 telescope.

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(apparent field of view in parenthesis)

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LUMICON 1.3" & 3.1" enhanced silver diagonal mirrors & 2" star diagonal.

The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed pyrex flat to 1/8 wave.

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2.14"...**$47.50** 2.60"...**$59.50** 3.10"...**$79.50**
4.25...**$129.50**

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90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

1¼" (1.32" mirror) **$79.50**
2" (1.83" mirror)(see photo above) ..**$119.50**

NEW ADJUSTABLE PIGGYBACK MOUNT

LUMICON has just designed a new adjustable piggyback mount ideal for all telescopes of 8-14" aperture. It has **both** vertical and sideways adjustment to allow optical alignment. It was designed to allow mounting of the LUMICON SUPER-FINDER on C-8, C-14, etc, but is ideal for any telephoto lenses or small telescopes.

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MODEL 100 HYPER-KIT for 35mm film, rolled-up. *Takes longer,* but it easy to use. Not recommended for 2415........**$225.00**

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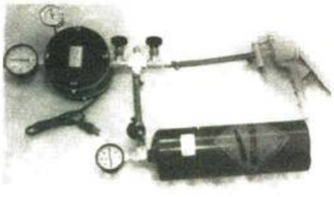

MODEL 600 HYPER-KIT [See Photo] Like the Model 300, but also sensitizes 120/220 larger format film and small glass plates **$299.50**

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For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**

CASSEGRAIN EASY-GUIDER.......**$199.50**

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For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER **$359.50**
48mm DEEP-SKY Filter ordered with any EASY-GUIDER [SAVE $20] ......**add $79.95**

WHAT DO YOU NEED?

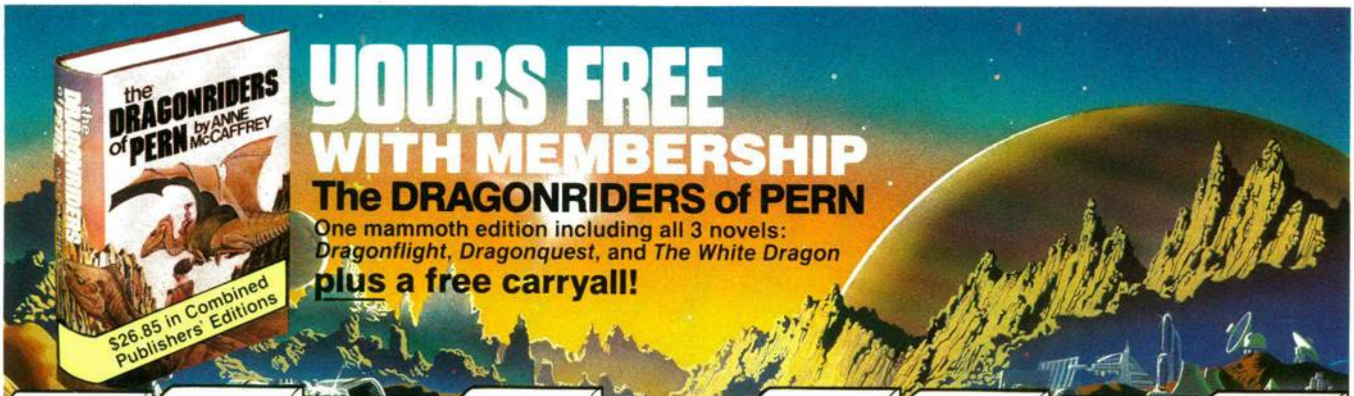
1. Hypersensitized Film. Use a LUMICON HYPER-KIT to insure a fresh supply, or use film pre-sensitized by LUMICON.
2. LED Illuminated reticle eyepiece system and battery pack, dual crosslines ...**$59.50**
3. Telescope with good drive. (See above)
4. Piggyback adapter (state telescope type)...**$25** Deluxe adjustable **$39.50**
200mm f/3.5 multicoated lens........**$99.95**
5. Filtration is essential for all lenses. Use hypered 2415 and the H-Alpha Pass Filter. For III a-J or color, use the Minus Violet Filter or the LUMICON DEEP-SKY Filter.
6. Off-axis guider is **essential** for consistently good prime-focus astrophotography.
7. Dual-axis drive corrector and electric declination (state telescope type)......**$259**

Kodak
TP 135-36
Fujichrome 400
Kodacolor VR
1000

HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. For fine grain B&W film use 2415. The fastest color films are Fujichrome 400 for slides and Kodak VR1000 for prints. Use VR1000 for galaxies and Fujichrome 400 for nebulae.

Film Type (35mm unless marked)	Exposures	Price
2415, Ultra-fine B&W, red sens	36	$9.95
VR200 fine grain color negs	12	$9.95
Fujichrome 400, "Excellent"	20	$12.95
VR1000, fastest of all, color negs	12	$12.95
5072, color slides from negs	36	$6.95
D-19 B&W Developer, 1 gal.		$5.95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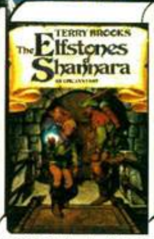
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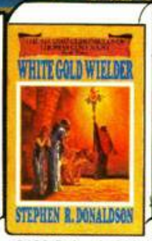
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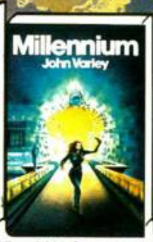
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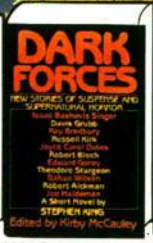
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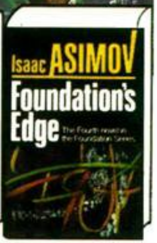
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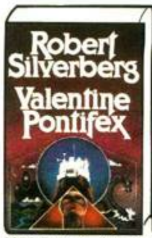
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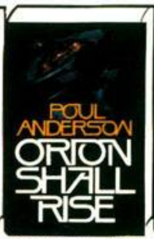
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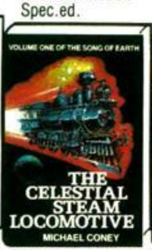
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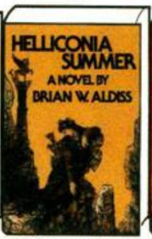
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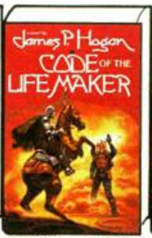
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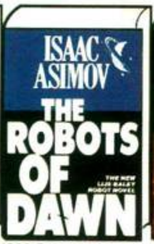
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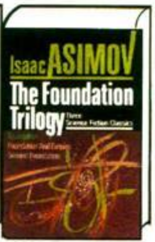
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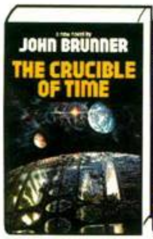
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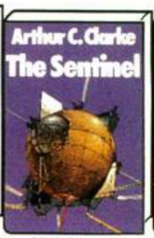
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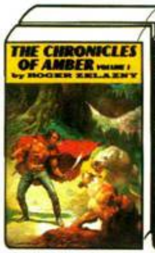
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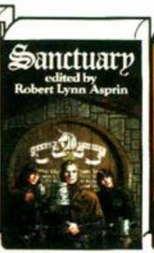
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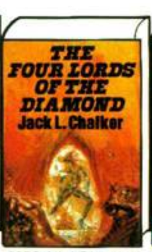
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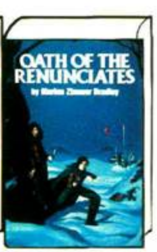
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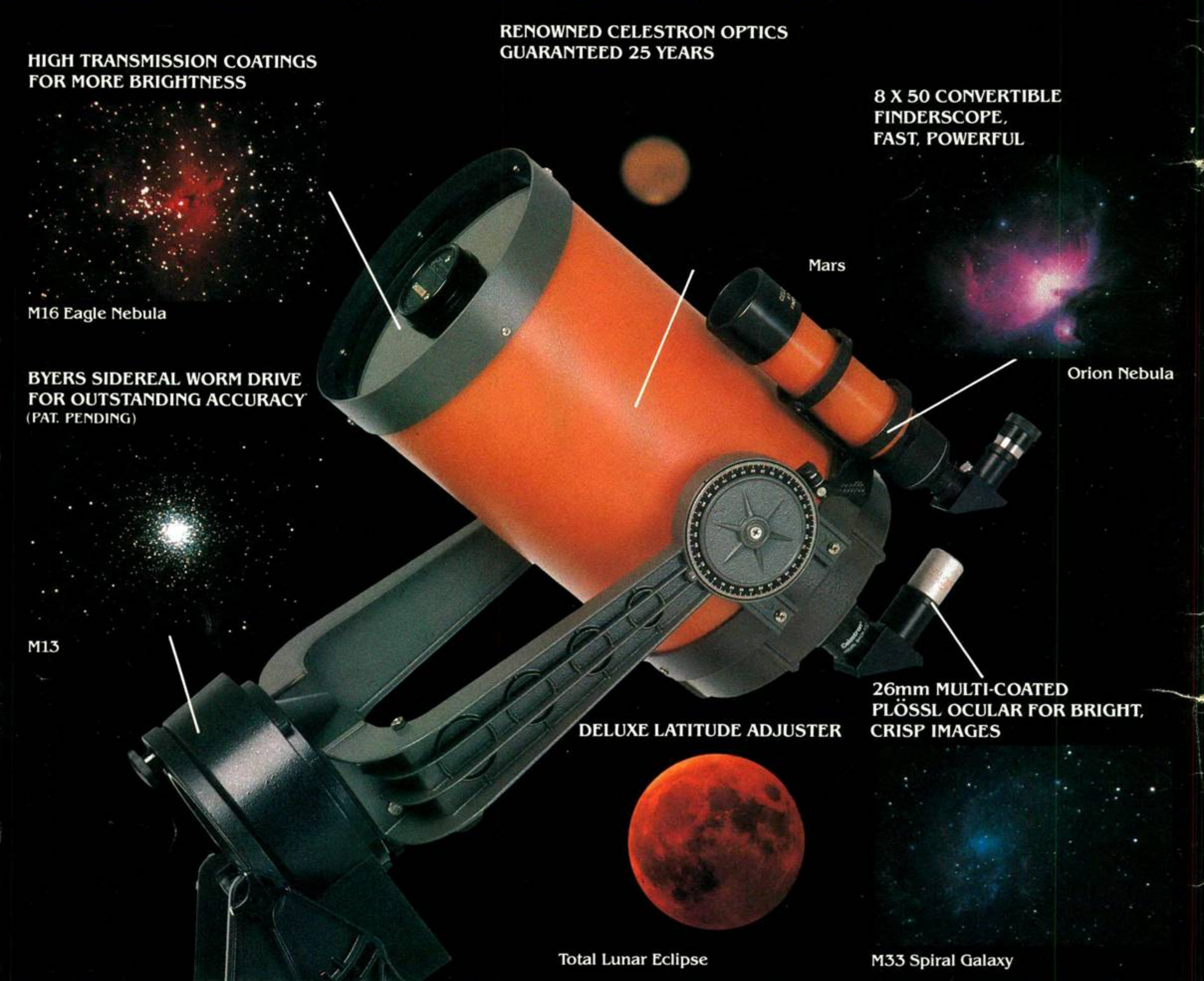
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